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REPORT

TO THE

SCIENCE AND ART DEPARTMENT OF THE COMMITTEE OF COUNCIL ON EDUCATION

ON THE

ACTION OF LIGHT ON WATER COLOURS.

Presented to both Houses of Parliament by Command of Her Majesty.

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Great Britain. Dep't of Science and Art

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PREFACE.

In April 1886 the Lords of the Committee of Council on Education requested Dr. Russell, F.R.S., and Captain Abney, R.E., F.R.S., to carry out an exhaustive series of experiments on the action of light on Water Colour Drawings. These gentlemen having expressed their willingness to undertake the investigation, the sanction of the Treasury was obtained to the expenditure of a small sum of money for the provision of materials and in the payment of a student in the Art Training School for the preparation of the necessary tints.

Shortly afterwards a resolution of the Royal Society of Painters in Water Colours was received urging "the " desirability in the interests of Water Colour Painters, " of the appointment of a Water Colour Painter in " association with Dr. Russell and Captain Abney in the " work of investigating the effects of light of various kinds " upon Water Colour pigments."

Thereupon their Lordships of the Committee of Council passed the following minute, dated 12th June 1886 :—

"Seeing the interest that the question of the action of light on Paintings in Water Colours has excited, and the great importance of that question to Artists in this country; it appears to my Lords desirable that there should be a representative Committee of Artists appointed to consider the matter from the Art point of view. Request the Royal Society of Painters in Water Colours and the Royal Institute of Water Colour Painters each to name two representatives to serve on a Committee, which Committee my Lords will themselves invite some other distinguished painters to join.

"Request Dr. Russell and Captain Abney, who have already undertaken to investigate as a scientific question the action of light on the various pigments used in painting, to inform the Committee of the method and nature of their inquiry.

" When the Committee have this information before them they will be in a position to judge whether there are any further points they would desire to suggest for investigation to Dr. Russell and Captain Abney or whether there is any investigation which the Committee would themselves wish to carry out."

The Committee thus appointed consisted of:—

Sir F. Leighton, Bart., P.R.A., *Chairman.*
Mr. L. Alma Tadema, R.A.
Mr. T. Armstrong.
Mr. Sidney Colvin.
Mr. Frank Dillon.
Mr. Carl Haag.
Sir James D. Linton.
Mr. E. J. Poynter, R.A.
Mr. Henry Wallis.
Mr. Arthur Torrens, *Secretary.*

This Committee have held four meetings, and Dr. Russell and Captain Abney have had numerous communications with individual members, from whom they received valuable information on the subject of their inquiry.

Their first report, now presented, and dealing with the physical effects of light on water colours—the investigation into the nature of the chemical changes involved being deferred to a second report—was carefully considered by the Committee of Artists, who unanimously adopted a resolution, which was communicated to my Lords, that the Committee accepted the first report, and desired to record their sense of its very great value and of the thoroughness and ability with which so laborious an inquiry had been conducted. And further that they were of opinion that it would be of great advantage if the experimental research, which Dr. Russell and Captain Abney have been conducting into the action of light on water colours, were extended to its action on colours when used with oil and other media.

By Order,
J. F. D. DONNELLY.

Science and Art Department,
30th June 1888.

FIRST REPORT

BY

DR. W. J. RUSSELL, F.R.S.,

AND

CAPT. W. DE W. ABNEY, C.B., R.E., F.R.S.

Part I.—Introduction.

Division of the investigation.

I. An investigation of the cause of the fading of colours naturally divides itself into at least three parts. First, the nature of the optical changes; second, the nature of the chemical changes; and third, the causes which initiate and accelerate these changes. To carry out such an investigation necessarily requires much time, many of the changes, more especially the chemical ones, can only be brought about by brilliant sunlight, acting for a considerable length of time. We have therefore divided our report into two sections, the first of which we now present. In it we have confined ourselves to the first division of our subject, the nature of the optical changes, and in some measure to the last division, reserving for our supplementary report a description of the results obtained in the second division. From the experiments described in this report certain obvious conclusions can be drawn, and these we shall indicate in due course.

Nature of colour.

II. Before giving our results we have thought it advisable to make a few preliminary remarks on the optical properties of pigments and the different characters of light to which they may be exposed. Colours are popularly talked of as greens, blues, reds, &c., and to these distinctive appellations are added by artists. Thus they talk of emerald green, cobalt blue, Venetian red, &c. Though to some extent to the trained eye an idea is thus given of the hue and luminosity of the colour, yet to the scientific experimentalist, the definitions of colours require supplementing, and in estimating any change which may take place in them an exact quantitative value of each is a desideratum. As to why a pigment is coloured science has hitherto not furnished a satisfactory answer, nor for the inquiry which we have undertaken is it at all necessary that an answer should be given. The question, however, as to how a pigment produces the impression of colour is one which can be answered. Colour is due to the selective action of the pigment, or stain, on light. That is to say, the rays of certain wave lengths (or colours) are transmitted and reflected by each pigment, or stain, in a more or less perfect manner and the others are absorbed. The transmitted and reflected rays will be shown to be identical—except in certain cases which it is unnecessary to consider here—and it is to these that the colour of the pigment is due.

Colour of pigments illuminated by the spectrum.

III. If we decompose a thin slice of white light into its component colours by means of a prism we get what is known as the spectrum, and if we allow this variegated band to fall on a white surface, such as white card or a surface of zinc oxide or barium sulphate, that surface becomes luminous where the colours fall, and they are presented to the eye with the greatest brilliancy possible. If, however, for the white surface we substitute a surface covered with some coloured pigment we at once perceive a difference. That which is generally supposed to be the colour of the pigment is lost and we have a stripe of the surface illuminated with the different rays of the spectrum, but their different colours are presented to the eye with their brilliancy unequally reduced. Probably no one coloured ray is reflected with the same brilliancy as it was from the white surface, and a large part of the spectrum is very much dimmed. In other words the pigment does not reflect any component of white light with the same intensity as does the white surface. If by proper means we collect the different coloured rays of the spectrum reflected from the coloured surface, and recombine them, we get back again the colour of pigment. If we measure the brightness of *each colour* reflected from the pigment in terms of the brightness of the same colours reflected from white paper, we have a quantitative measure of the light reflected from the pigment, such light being that by which the pigment produces the impression of colour. Thus, if we measure the light reflected from cobalt blue in the various parts of the spectrum, we may produce the colour of cobalt on white paper by reducing in proper proportions the different rays of the spectrum formed by white light, and then recombining them. The colour of a pigment, we may say, is dependent on the amount of the components of white light which it reflects back to the eye.

Further it will be seen that no matter what the source of light may be,—whether the yellowish-white light of gas, the purer white of the electric arc light, or of the sun, or the bluer white light from the sky,—the comparative measures of the brightnesses of the different colours reflected from the two surfaces will always be the same. Thus, if the spectrum formed by gaslight be used, and the brightnesses of the different parts of the spectrum reflected from a white surface and from a coloured surface be compared, the comparative values of the different rays thus obtained will be the same as if the source of light had been the sun. To see what will be the colour of a pigment by gaslight, the rays of the spectrum of gaslight must be reduced in the proper proportion found for the particular pigment, and be again recombined, and this will give the colour of the pigment seen by gaslight. In the same way, if the spectrum be formed by sunlight, the different parts of that spectrum must be reduced in exactly the same proportion, and the recombined spectrum will give the colour of the pigment as it would be seen in sunlight. Careful measurements of the various simple and mixed water colours which are usually employed by artists have been made and are given in Part III. The source of light employed was the electric arc light, and the relative intensities of the different coloured rays were measured by a method which one of us with Major-General Festing, F.R.S., has described in a paper recently read before the Royal Society.

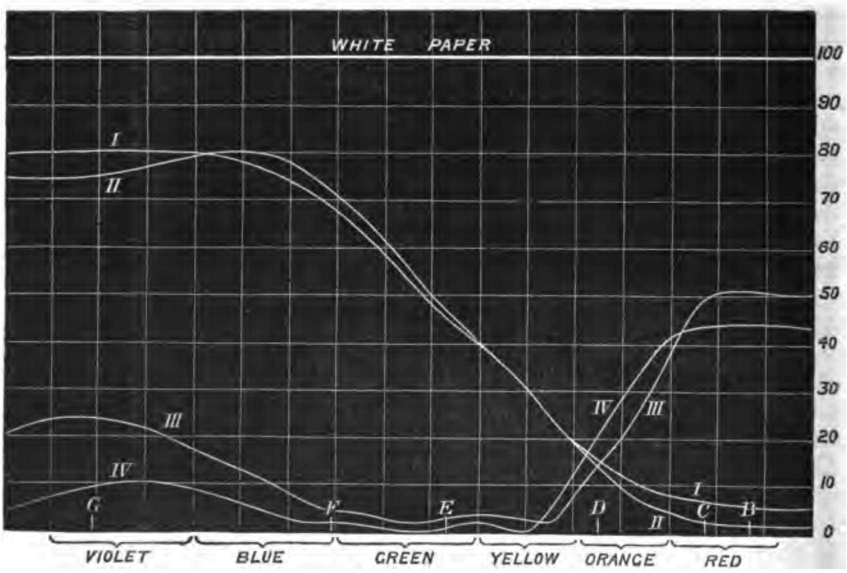
Production of colour.

IV We will now trace the sequence of phenomena which happen when white light falls on a coloured surface. Colours may be divided into two classes, those which are insoluble and those which are soluble in water. Many of the soluble colouring matters are precipitated as lakes, and the same arguments hold good for these as for the solid pigments. In the case of an insoluble pigment a ray of white light falls on one of the particles, but only some components of the light can pass through it, and it emerges after its passage as coloured. This strikes the next particle and part is reflected back, reaching the eye as coloured light, but part penetrates through the next particle. This in its turn is partly reflected back and partly transmitted, and so on. At the same time, however, a certain amount of white light is reflected from the surface of the particles and mixes with the coloured light which has passed through one or more particles. Hence the colour of a pigment always contains a certain per-centage of white light, together with the coloured light. Thus the colour of Prussian blue is principally due to the transmission through the particles of a large proportion of the violet blue and blue-green rays, together with a small quantity of white light reflected from the surface of the particles to which the original light falling on it had direct access. It may be remarked that when thin washes of these colours are washed over white paper the number of coloured particles are comparatively few, and that the white paper reflects relatively more white light to the eye. A microscopic examination of such a surface reveals this fact in a very interesting manner. The colour is therefore less intense in hue, and whiter. The nearest approach to the real colour of a water-colour pigment is seen when a mass of the moist colour is on the pallette, the white light reflected being then at its minimum. The same argument applies to those colours which are soluble, and which, consequently, we may take to be continuous. The light which penetrates such a colour will be of the same hue as that reflected to the eye from the paper. The white light passes through the stain, loses certain portions of the original spectrum colours, is reflected from the white paper beneath, and is once more transmitted through the colour, reaching the eye as a coloured light. Thus the colour of the carmine (cochineal) is due to the transmission by the dye of most of the red and a good deal of the blue of the spectrum of white light. The effect of mixing a white with a coloured pigment is to cause more white light to be reflected, and thus to give a pale and less transparent appearance to the colour.

Identity of the light reflected from, and transmitted by, pigments.

V. It may be of interest to compare the light reflected from colours with that transmitted by them. The following diagram will give the results of two such colours, Prussian blue and Carmine.

Fig. I.



NOTE.—The letters in this and in all other diagrams refer to the principal Fraunhofer lines of the solar spectrum.

Curve I. is the light reflected from Prussian blue after deducting white light.

Curve II. is the light transmitted through Prussian blue.

„ III. „ reflected from Carmine.

„ IV. „ transmitted through Carmine.

In the Prussian blue the reflected and transmitted light are very nearly identical, but in the Carmine the transmitted light was less than the reflected. The small difference in the first case and the larger difference in the second is due to the fact that the depth of colour in the reflected and transmitted lights was not equal.

The dark rays and the energy of the spectrum.

VI. In the analysis of white light by the prism we have only so far mentioned those radiations which are visible, and which are called "light." These have been considered first, as it is these alone from which a pigment derives its colour. But there are other radiations which coexist with the visible radiations, and though invisible to the eye may have to be taken into account. Of these invisible radiations some lie beyond, or, as it is generally termed, below the red in the spectrum, and some beyond, or above the violet. Those which are below the red, and have a longer wave length, experiment has shown to possess more energy or capacity of doing work than all the radiation ("light") above the red. What that work may be we shall touch upon briefly later on. It would be beyond the scope of this introduction to show how the comparative energies of the radiations, visible and invisible, forming the spectrum can be measured. It will suffice to say that by allowing the different parts of the spectrum (light and dark) to fall on an undecomposable substance (lamp black) which can absorb them all (or very nearly all), the measurement by thermo-electric means of the rise in temperature of the lamp black produced by the different parts of the spectrum gives a comparative measure of the energy of radiation of these parts. It must be remembered that the energy of the slice of white light decomposed by the prism, and which includes the invisible radiations, is the sum of all the energies of the different radiations of the spectrum.

Figure II. shows the comparative energies at different parts of the spectrum of sunlight, the electric (arc) light, and an incandescent light which is the same as that of gaslight. The heights of the curves denote the energies at different points of the spectrum produced by means of a prism.

Luminosity and energy of the spectrum.

VII. Figure III. gives the luminosity of the different rays of the spectrum of sunlight on a day in July, of the electric light, and of gaslight. The ordinates or heights of the curves show the comparative brightness to the eye of the light at the different parts of the spectrum.

Fig. II.

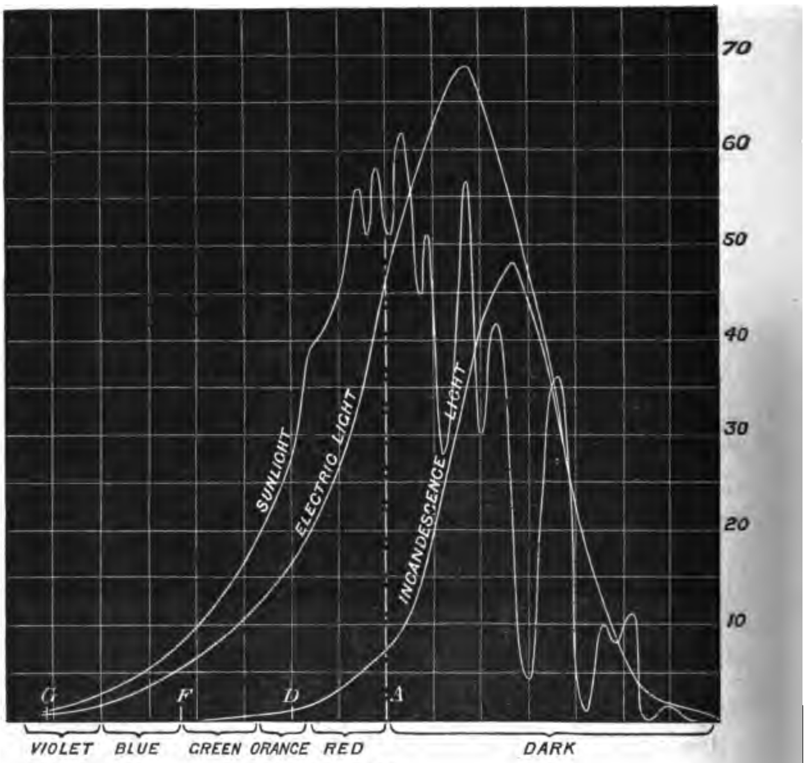
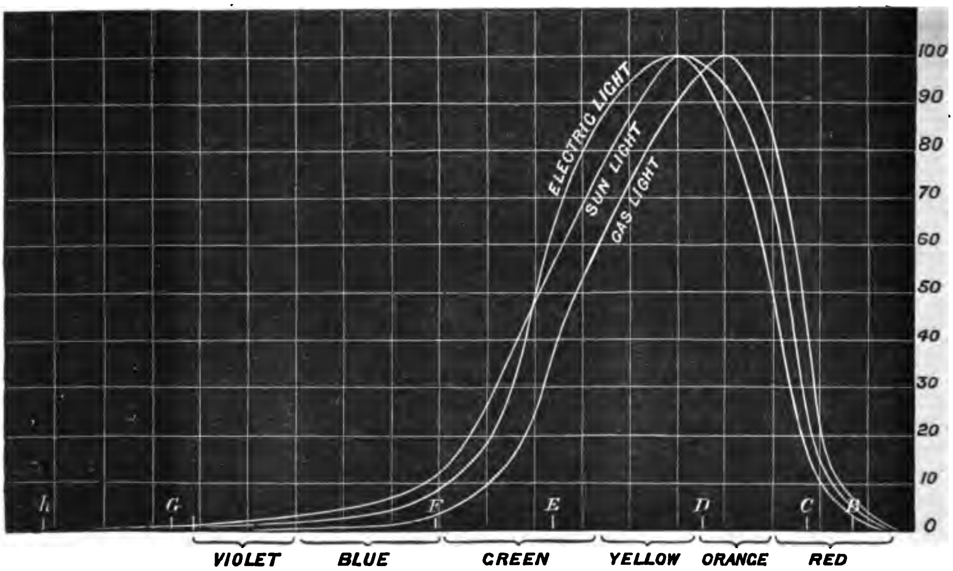
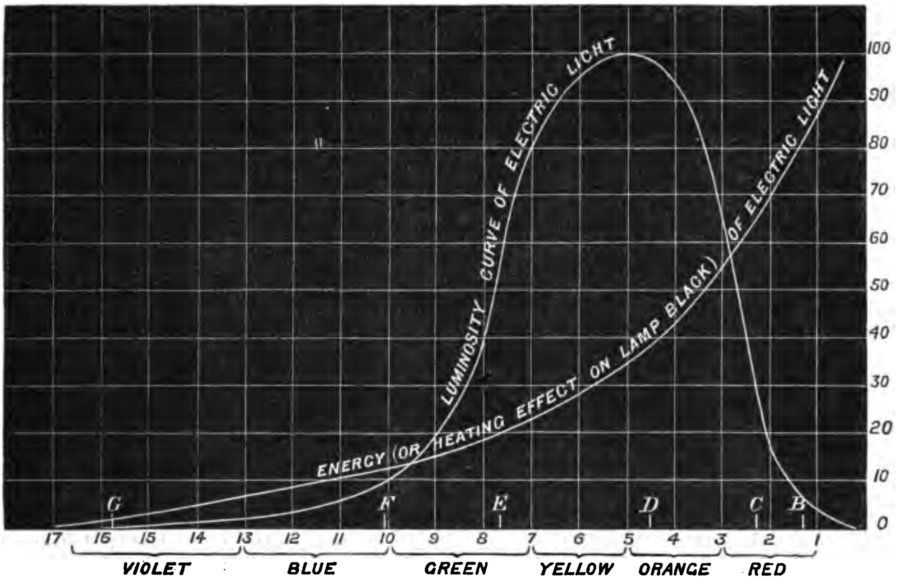


Fig. III.



In Figure IV. we have shown the portion of the energy curve of the electric (arc) light of the visible part of the spectrum together with its luminosity curve, and it needs but a glance to show that the brightness of the visible spectrum bears no sort of relation to its energy. The brightest part of the visible spectrum is in the yellow; whilst, as before said, the point of maximum energy is just below the red. Had we used the luminosity and energy curves of any other source of radiation we should have arrived at exactly the same result.

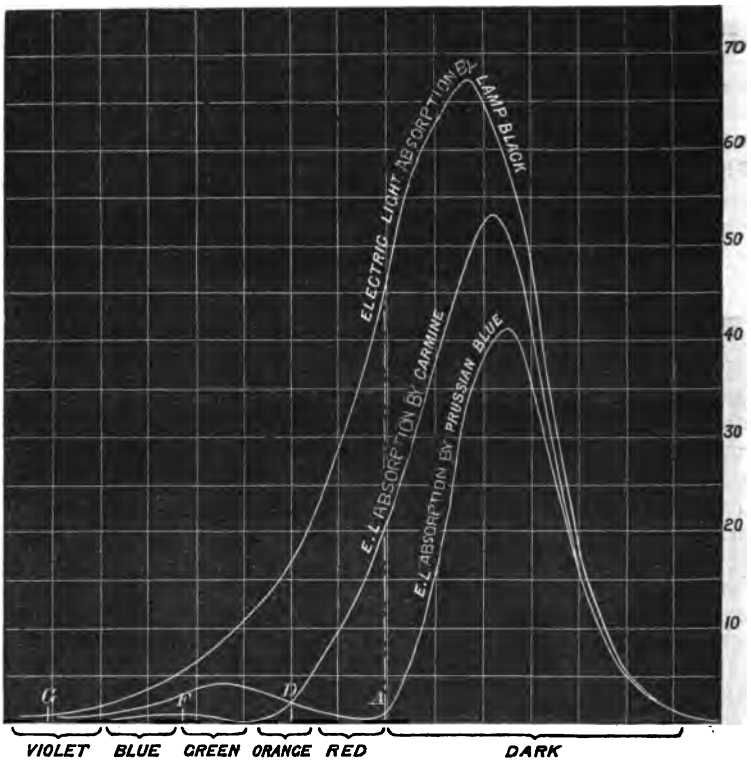
Fig. IV.



Reflection of dark rays.

VIII. The dark rays when falling on a pigment behave in exactly the same manner as those which are visible; some disappear, and others are transmitted, and though they give no colour to the pigment (it would appear of the same colour if they were excluded) are just as much in the reflected light as those rays which are visible. We have shown that the light which is transmitted through a pigment is of the same general character as that reflected, and the same holds good for the dark rays. Fig. V. will give an idea of the total rays which are transmitted and reflected by Prussian blue and carmine as measured, *not by their brightness, but by their energies*, using the method indicated in Fig. VI. The top curve shows the energy of the original light, and the difference in heights between this curve and the two inner curves will give the energies of the rays reflected from the two pigments.

Fig. V.



It will be seen on comparing the two innermost with the outer curve that in the Prussian blue there are very few rays in the red, yellow, and green, which are transmitted and consequently reflected, but that in the dark rays we again have a transmission of radiation. In the case of carmine more of the red is transmitted and less of the dark rays.

The energy existing in the invisible region beyond the violet is very small, but since all radiation consists of a wave motion in what physicists have called the ether, it may happen, and does indeed happen, that the wave period of this portion of the spectrum is of such a nature as to cause a destructive vibratory motion on the atoms of the molecules of the pigment on which the light falls. It is necessary, therefore, to take this action into consideration.

We are now in a position to see that all radiation, visible and invisible, is not reflected or transmitted through the various pigments, and the question arises as to what has become of the rays which are apparently lost. The radiation which is not reflected from the colouring matter has disappeared in passing through it; in other words the pigment has absorbed certain of the radiations visible and invisible, and with very close approximation to the truth it may be said that the rays absorbed are complementary to those reflected. Hence in Prussian blue (*see* Fig. I. & V.) the rays absorbed are principally in the dark part of the spectrum, and in the red and yellow, and partly, but in a minor degree, in the green, blue, and violet. Similarly in carmine, the rays absorbed are principally in the dark part, the yellow, and the green, of the spectrum, and less in the blue and violet of the spectrum.

Absorption and "work."

IX. Now it is a received axiom in physical science that in any body which absorbs radiation the energy so disappearing performs work of some kind in that body. The work so done is a raising the temperature of the body, a chemical decomposition of the body, or a re-arrangement of its molecular condition, as for instance in the iodide of mercury. Each kind of work may be done at the same time, but the energy which is expended on one form, cannot be again expended on another form, of work. On elements such as carbon, gold, &c., the work done only raises the temperature of the body above that of the surrounding objects, but in chemical compounds, such as nearly all the pigments in use are, there may be besides a chemical decomposition. The chemical decomposition of a colour means a fading or an alteration in its colour, but the raising of its temperature to the small degree which the visible (light), or invisible, radiation to which it is ordinarily exposed can effect, does not alter its composition or colour. That the temperature above that of the surrounding objects to which a colour can be raised, even by sunlight, when *freely exposed*, is small is not only shown by theoretical reasoning, but by direct experiment. In the case of a wash of water-colour, the particles on which the radiation falls are very small, and they consequently have a large surface compared with their volume. As the rapidity of loss of temperature in equal volumes under the same conditions is in the ratio of the radiating area, it follows that the loss of temperature by radiation in the small mass is very nearly equal to its gain. In other words there is an equilibrium of temperature established which is but very little higher than the temperature of surrounding objects. When chemical decomposition takes place by light, however, the results are different. The decomposition once effected remains, and the quantity of the matter decomposed increases with the length of exposure. The outside of the particles is first acted upon, and then gradually (as light continues to act) the inner portions are decomposed, until finally the whole particle is changed. Evidently those colours, the effect of light on which is to bleach them, are the most rapidly acted upon. Again, too, the large area of the surface of particles, as in a water-colour, compared with their small volume, is favourable for the rapid effect of the action of light in altering their composition.

As work depends upon absorption, it is important to remember that when the radiation (light) is decomposed into its prismatic components it is only those rays of the spectrum which are absorbed that can do this work. Thus, if a pigment only absorbs in the red, it is only the red rays which can do work and no others, and so on.

Estimation of chemical action in a body.

X. In estimating the chemical action effected on a body by radiation there are thus two factors which have to be taken into account, viz., the intensity of the radiation acting, and the time during which it acts. To obtain the same amount of action in two cases the product of these two amounts must be the same. Thus if a certain tint be exposed to an intensity of radiation which we will call 100 and bleaches it in, say, one hour, then if a similar tint be exposed to an intensity 1, it will require 100 hours' exposure to it to effect the same bleaching. This has been fully proved by experiment. There is an idea abroad that if the light be very feeble a bleachable colour, no matter what length of exposure be given, will not fade. This, however, is not the case. The same proportion of the total energy absorbed by the body which, with an intense radiation, effects chemical decomposition, is expended with a feeble radiation in doing the same kind of work. To appreciate this we may very briefly allude to what the deductions from scientific experiment lead us to believe to be the manner in which light acts on the molecules of which a body is composed.

Action of "light" waves on atoms and molecules.

XI. In a compound body, the molecules must at the very least consist of two ultimate atoms, and these oscillate to and fro from one another, each atom having its own constant time of completing an oscillation, the molecule itself oscillating in a period of its own. It need scarcely be said that the time of these oscillations is not to be measured even by millionths of a second, nor the extent of the oscillation by the millionths of an inch, but by standards very far smaller. A ray of light of any pure colour is due to a continuous series of oscillations or waves of a known and measurable length in the physicists' "ether" which we have already mentioned. If it happens that the time of oscillation of some "light" wave agrees with the time of oscillation of one of the atoms, the length of swing of the oscillation of this last is increased with each beat of the ether, till, if the number of beats of the ether be sufficiently numerous—that is if the light be allowed to play upon the molecule long enough—the length of its swing is increased till finally the atom will swing off from the molecule, thus changing its composition. This liberated atom may join itself to the molecule of some other matter which may be present, such as oxygen or water. The amount of increased swing the waves of light can give the atom depends on the amplitude of the waves (the amplitude in a wave in the sea is the height from trough to crest), the square of which is a measure of their energy as it is of the intensity of the light. To take a very familiar example, suppose we have a heavy church bell hung without any friction on its supports, and without any resistance to its motion, and that when vibrating freely, it would make a complete swing once in a second. Suppose to the end of the bell rope was attached a small horizontal plate, and that at intervals of a second 1,000 grains weight of water fell from a fixed height on to the plate, the bell would gradually oscillate, and finally the oscillations would become so great that it would ring. If instead of 1,000 grains falling from the same height we had one grain of water falling every second it would take 1,000 times longer before the bell rung, and if it was $\frac{1}{1000}$ of a grain of water that fell every second it would take 1,000,000 times as long before it rang. The work done by the dropping water may be looked upon as the work done by the amplitude of the wave, and the church bell as the atom, moving without friction and without resistance.

Chemical action may be invisible to the eye.

XII. It will also be noticed that it is only those rays whose waves beat in unison with the oscillation of the atom which increase the swing of the atom. The wave motion is then destroyed, and that particular ray disappears, *i.e.* is absorbed. It must be recollected that the visibility of any change effected on a body merely means the number of molecules altered. In feeble light the numbers altered in a given time are much fewer than when light is intense. We have a good instance of this in a photographic plate, where the effect of the exposure for $\frac{1}{100,000}$ of a second to sunlight on a salt of silver is invisible to the eye, whilst a second's exposure is rendered visible. We know, however, that $\frac{1}{100,000}$ of a second's exposure to sunlight has chemically altered some minute portion of the silver salt on which it fell, as what is termed development proves it. Again, we have a further definite proof in the case of certain colours that the smallest intensity of radiation if sufficiently prolonged effects a chemical change in them. In photographic processes the chloride of silver is only sensitive, roughly speaking, to the extreme violet of the visible spectrum. When any one of certain colours which are fugitive are applied to stain the silver chloride, and the part of the spectrum which the colour absorbs is below the violet, then after exposure in the spectrum on applying a developer, as it is called in photography, the action of the spectrum in decomposing the colour of the dye is shown by a deposit of silver taking place in that part which the colour absorbs. Thus, if carmine (cochineal) be applied to the chloride of silver an action will be shown to take place in the green where the colour, as will be seen, absorbs. It must be remembered that without that colour no such deposit would be possible. The spectrum of sunlight will cause this phenomenon to appear in a few seconds, and the spectrum of skylight, or of candlelight will equally cause it if the exposure is prolonged. That is to say a feeble radiation (light), if sufficiently prolonged, will give the same effect as a radiation (light) which is several thousand times as intense. And it further demonstrates that chemical decomposition takes place in a colour long before such change is visible to the eye.

The heating effect on a body may be taken to be an increase in the amplitude in the oscillations of the molecules rather than of the atoms (though the two are closely connected), pointing to the fact that the shorter wave-lengths which have a greater rapidity of oscillation are those which would be most likely to increase the amplitude of the oscillations of the atom, and thus to produce a chemical change in the body. We shall see further on that this the case.

Light to which water colours are exposed.

XIII. As to the light to which pigments in water-colour drawings are ordinarily exposed in a room, a few remarks must be made. There is no doubt that pictures are, as a rule, carefully protected from direct sunlight, but it is nevertheless true that the greater portion of the light they receive is reflected sunlight. On a bright day clouds reflect sunlight, and on a dull day the principal part of the diffused light is also sunlight which is reflected according to the laws of geometrical optics from particle to particle, a certain percentage eventually reaching the earth through the clouds. There is of course also a fair proportion of the light due to the sky, and this light is bluer than reflected or diffused and weakened sunlight. In cases where the windows of a gallery are in the vertical walls and have an uninterrupted view of the horizon, the blue light reflected is comparatively small, the light near the horizon being distinctly more like sunlight than is that nearer the zenith. In galleries lighted like those at South Kensington by skylights the light to which pictures are subjected is on the whole bluer. The artificial lights to which water colours are exposed are gaslight, the arc, and incandescence electric lights, and as we shall see presently the first and last are very deficient in blue rays.

Choice of light for experimental work.

XIV. In conducting our experiments it became necessary to choose the light which would most readily adapt itself to giving a clue as to which colours were affected by exposure in a time which would be measured by months instead of by years. A careful consideration led us deliberately to avail ourselves of as much sunlight as we could secure in this rather sunless climate of ours, together with the diffused and sky light, when sunshine was absent, which would act less energetically. We are aware that writers have expressed themselves as disinclined to accept deductions as to the fading of pigments when exposed to this bright light of the sun, but they have, as far as we are aware, never given any serious reasons for their disinclination. Their arguments have usually been based upon their own convictions rather than on experimental proof of any kind, or if experimental proof has been quoted from other writers, half the truth or more is most frequently and probably unwittingly concealed. Probably, however, they express what is in the minds of many, so we shall enter somewhat fully into the arguments which decided us to adopt the step we did.

Cause of the difference in colour of various lights.

XV. To the eye the hue of the lights mentioned above undoubtedly differ considerably, and unless the cause of the difference had been tracked out experimentally, and with scientific exactness, it would have been unwise to have chosen out any one of them with which to conduct experiments, since the results obtained with it might not be applicable to any other. Happily, however, for such work, the spectroscopic analysis of light furnishes irrefutable evidence that from the results obtained from exposure to one light, correct deductions may be made as to what would happen were the exposure made to another. If, by a prism, we analyse all the different kinds of light mentioned above, we find that in the visible spectra so obtained no colour is absent,* but if we compare the intensity of the same colours in the different spectra we find that there is a variation. For example, if we compare the spectrum of sunlight at mid-days in May with gaslight we find that there is considerable less violet, blue, green, and yellow light in the latter than in the former, and in light from a blue sky considerably less red and yellow. The following diagram shows the proportions in each colour.

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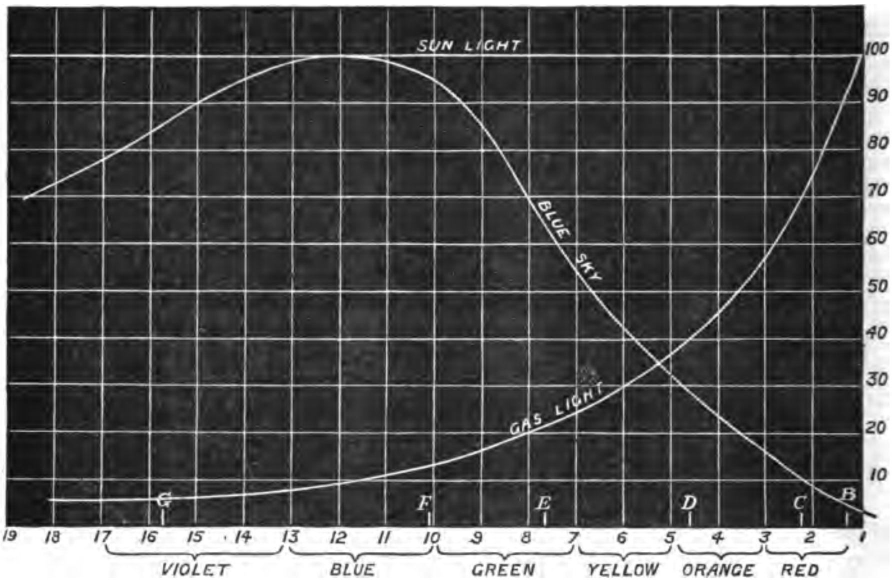
* We are not here taking into account the Fraunhofer lines, which in sun light and sky light are present. Even in these there is diminished radiation present.

Fig. VI.



The intensities of the spectrum colours of sunlight near mid-day in May are not very different from those of the electric (arc) light, whilst the intensities of the colours of the incandescence electric light when rendered normally incandescent are a very close approximation to those of gaslight. The above diagram indicates in a striking manner that the light of the gas and therefore of the incandescence electric lamp, is yellower than that of sunlight, and therefore of the electric (arc) light, owing to the increasing diminution of comparative intensity of the colours from red to violet, whilst the light from the sky is considerably bluer than that from the sun. One of us has shown recently how by cutting off from the electric arc light (or from sunlight of known composition) the proper proportions of the different spectrum colours, the exact hue of gaslight or skylight can be produced.

The difference in hue of the light from any of the sources we have been considering we may repeat is due to an excess or defect, but not to a total absence of intensity of the different parts of the spectrum. As regards the dark rays of the speetrum the same argument holds good. Fig. II. will enable a judgment to be formed of the different proportions of dark rays in sunlight, the arc light and gaslight. In light from the blue sky the proportion of dark rays is much smaller, and no very accurate measurement of their intensity has been made, but as it will shortly be shown that the rays below the red do not cause chemical change in any of the pigments we have tried, this want of accurate knowledge is of no great moment in the present instance.

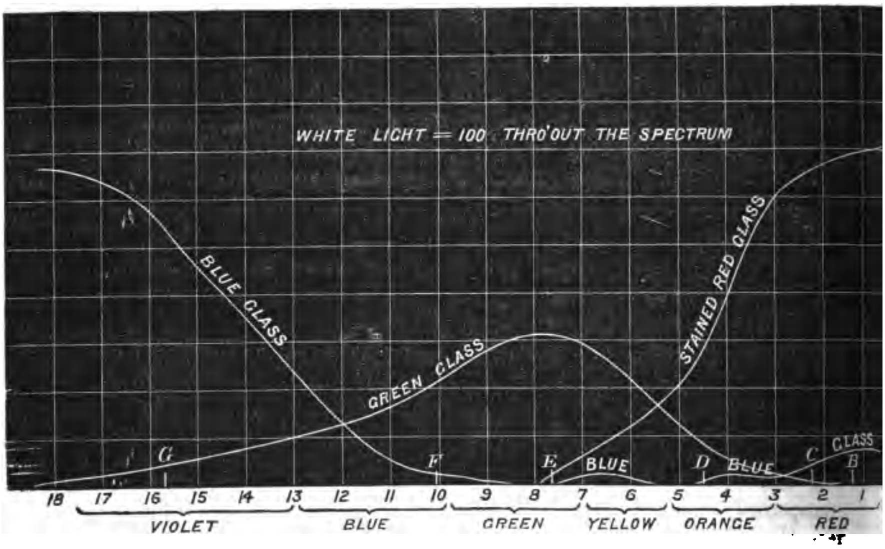
Results from one source of light can be applied to another source of light.

XVI. Since, then, all sources of light emit the same rays, but of different intensities, which can be measured, it follows that if we know which rays are chemically active, and the amount of work which, when of a certain intensity, they perform, we can, from the work done by the light from one source, deduce the work that would be done by another. The most perfect manner of noting the action of light would be to expose for a given time the pigments to the action of the spectrum formed by an unvarying source of light, and to measure the amount of chemical action (fading of the colour in most cases) which had taken place in every part of the spectrum. When the relative intensities of the different parts of the spectra from other sources of light compared with this standard spectrum were known, then the length of time during which it would be necessary to expose the colour to any one of them to produce that same total effect could be calculated. Unfortunately for our experiments, even in full sunlight, which is the most powerful light we can work with, months are often required to effect a visible chemical action on some of the pigments; it was therefore useless to take a narrow slice of light, say $\frac{1}{10}$ inch in width, and $\frac{1}{2}$ inch in height, and form a spectrum with it on a surface of coloured paper four inches in width and one-half inch in height, and wait to see when the bleaching took place.

Use of coloured glasses in the experiments.

XVII. To avoid this impracticable method resort was had to the use of coloured glasses to ascertain the part of the spectrum which was most active in producing the fading action. The glasses used were red, green, and blue. It may be well here to say something regarding what is meant by the terms red, green, blue, &c. as applied to glasses. It is a very popular idea that light coming through coloured glass is really white light, which is in some way transmuted into red, green, blue, &c., as the case may be. There is no transmutation. The effect of colour is merely produced by the abstraction of certain rays, or of a proportion of them, from the white light by the material of which the glass itself is composed. The following diagram shows the different parts of the spectrum, and the intensities of the rays which the above glasses transmitted, taking the spectrum colours of white light as unity throughout.

Fig. VII.



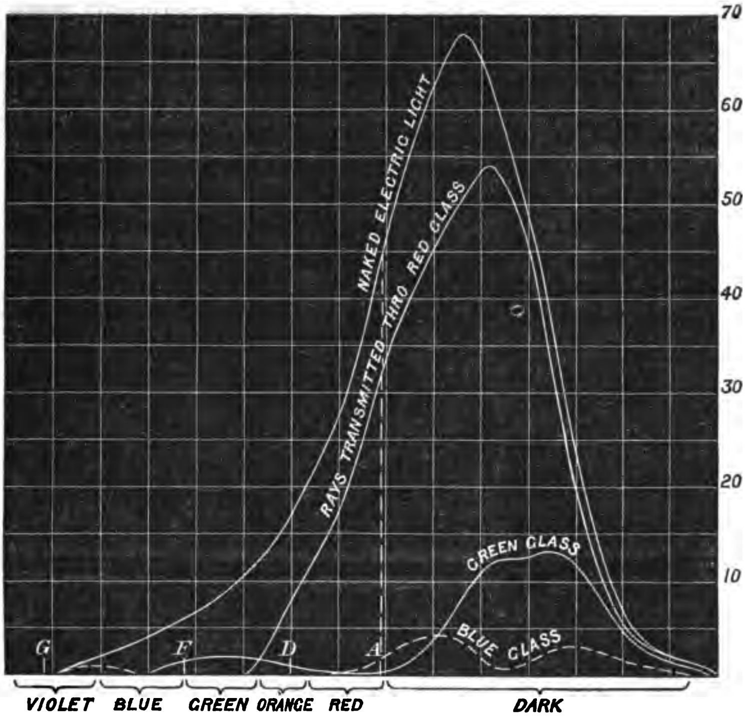
The difference between the heights of the three curves and the line which would occupy a horizontal position at 100 on the vertical scale had the diagram been continued up and which represents the intensity of the different colours forming the original white light before passing through the glasses will give the amount of the different rays cut off. A table of these curves will be found in Part III.

Practically the visible spectrum was divided into three parts, and a reference to the table of colours will show that in every case where any fading took place it was always found beneath the blue glass, very much less often and to a far less degree under the green, and only twice under the red glass, and was then barely perceptible. The blue glass also allows most of the dark rays beyond the violet to be transmitted. Experiment has shown that these rays are chemically active, but not to the same degree as those which are visibly transmitted through the blue glass. This might be expected as their energy or capacity of doing work is far less.

Proportion of dark rays transmitted through the coloured glasses.

XVIII. The following diagram will show the proportion of dark rays which pass through the different glasses.

Fig. VIII.



They are nearly entirely transmitted through the red glass, very slightly through the blue and green glasses. Had the fading of the colours we have examined been due to the dark rays, it ought to have been shown beneath the red glass far more than under the green or the blue glass. This was not the case, as a reference to Table VIII. will show. We may therefore say that the blue, violet, and ultra violet rays are those which are by far the most active in producing a change in the pigments with which we have experimented.

As the intensity of the different rays of the spectrum coming from the different sources of light have been measured, it follows that the total intensity of the rays from each source of light transmitted through the blue glass can be calculated. We may take these total intensities as a very close approximation to an inverse measure of the time to which the colours would have to be exposed to produce an equal result as regards fading.

Joint effect of heat and light.

XIX. It might very properly be objected that although it has been shown that the dark rays do not affect chemical decomposition, it has not been proved that the heating effect they have on a pigment might not aid the rapidity with which the decomposition takes place. Direct experiments were undertaken with this object in view. The backs of papers coloured with pigments which we have proved to be fugitive were placed in contact with a tin containing boiling water and exposed to light, together with similar papers merely resting against wood. Some few of those colours which are affected by heat without light in an atmosphere *saturated with moisture, see* page 28, did fade with very slightly greater rapidity where exposed as above, but with the majority the rate of change was, if anything, slower. Further experiment has also shown that if the dark rays be cut off from sunlight by proper means the rate of fading in colours freely exposed is not diminished. In our experiments in the open tubes which will be described presently, the temperature was only a very few degrees higher than the temperature of outside atmosphere, and therefore the experiment made by heating the pigmented paper by contact with a vessel at the temperature of boiling water was an extreme example of the effect of heat. A reference to the results of experiments shows that damp is often a factor in the rapidity of fading, and as heat tends to lessen the moisture present in the paper and pigment, it might be expected that in the majority of cases fading would result more slowly when the pigment was heated whether by radiation or by heat applied as above.

Deductions made from the cut that chemical changes take place in the blue rays.

XX. That fading should principally take place in the blue rays was to be expected, from experiments that have been conducted with other objects, and is of great practical importance. We have already stated that it is only those parts of the spectrum which are absorbed by a colour that can do work on it. Of all colours, the reds, yellows, and greens absorb principally in the blue part of the spectrum (*see* diagrams of colours), and the blues much less. Hence we may expect that the former pigments would fade more rapidly than the latter if they are fugitive. And what is more important, it locates the action of the spectrum to the region which is least luminous, and which varies enormously in the different kinds of light to which pigments are exposed. Of the different kinds of daylight, viz., sunlight and skylight, to which water-colours are exposed, sunlight is the safest when reduced to equal intensity, since it contains a far less proportion of blue light than does skylight.

Fig. IX.

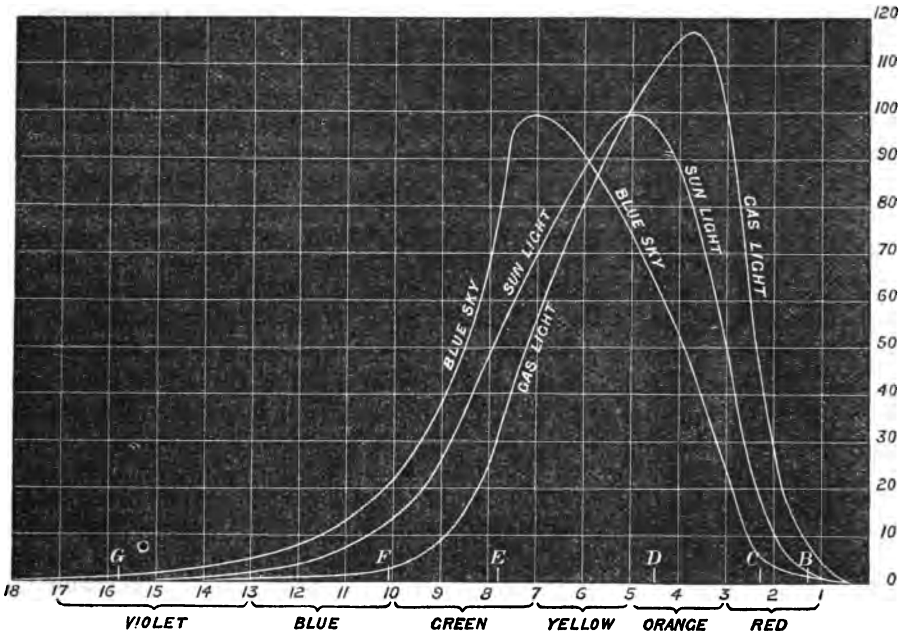


Fig. IX. shows the luminosity of each part of the spectrum for skylight, sunlight, and gaslight, derived from Fig. VI., when *the total illuminating effects of each to the eye are equal.* The relative energies (capacities for doing work) of the light which is transmitted by blue glass in three cases are: blue skylight, 112·0; sunlight, 57·5; gaslight, 5·7, or very nearly in the proportions of 20, 10, and 1.

Duration of the exposure given in the experiments.

XXI. We may now consider the amount of exposure given to our pigments, and thence deduce, within limits, the time that would be taken to produce a similar effect in the light to which they would ordinarily be exposed. Between the middle of May to the middle of August, that is, from the time when the exposures were first made to the time when the first series of readings were made, there was registered at Kew Observatory 705 hours of bright sunshine, and at Greenwich 652. We may therefore take it that there were about 675 hours of the same bright sunshine at the place in which our colours were exposed. Not only, however, did they receive this sunshine, but also the light from the sky. The total number of hours of effective daylight which they received in the same time was about 1,700 hours. We can make a very fair comparison between sunlight and skylight from the results obtained by experiment. When the sun is bright, we may take it that the sky is not overcast, but is fairly clear, and if, by photometry, we may measure the brightness of the total light from the sky and of sunlight, and of the skylight separately when illuminating a surface placed vertically and facing the direction towards which the papers were exposed, we can calculate the ratio of the brightness of sunlight and skylight. It would be manifestly of little use to take measures of the whole of the components of the light, for we have shown that if we take a unit of light of blue sky and a unit of sunlight, we have much more blue light in the former than in the latter. And, as it is the blue rays that we have shown to be effective in acting on those pigments which do fade, the photometry had to be confined to these rays alone. The average intensity of the blue rays in *direct* sunlight, (*i.e.*, with the receiving surface held normally to the direction of the sun's rays, is attained very nearly at 3·30, thus in the middle of August it is about ·63 of that of the maximum. In the case of our tubes, however, the pigments were not exposed so that the surface was normal to the direction of the sun's rays; but always with the surface vertical. As they were cylindrical, it might, at first sight, have appeared to be a matter of some difficulty to say whether the photometric measurements should be made with a vertical surface facing east, south, or west. A reference to the tubes themselves, however, solved the question, as it was found that the greatest fading took place in that part of the paper which was parallel to the building against which the tubes were hung, and it was this direction in which the surface of the photometer to be illuminated was placed. The conditions of exposure required that the effect should also take into account the reflection from the glass, and this was duly attended to. As a result, it was found that though the illumination by the sun near mid-day of a vertical surface facing 20° east of south was on an average nearly 4·5 times more intense in blue light than was the sky, yet there was a steady diminution in the ratio after about three hours on each side of when the maximum was attained; owing to the greater inclination the paper had to the solar rays and also to the increased reflection from the glass from the same cause. A table of the vertical intensity of sunlight at different times of the year will be found in Part III. It may be fairly taken that the average intensity of the blue of sunlight throughout the day is close upon 2·75 that of the average light from the sky. Although the sun, soon after its rising, shone upon the pigments, yet at about 3.30 in the afternoon they were shaded from the sunlight, and this reduces the number of hours' sun which they received to about 500 hours. The above average value of sunlight to skylight was taken with a knowledge of this fact.

Duration of exposure between May and August 1886, in terms of mean skylight.

XXII. We thus arrive at the conclusion that when the sun was shining for 500 hours, the pigments received blue light equal to 1,875 hours of that of a blue sky fully illuminated when the sun shone on them. Besides this, the pigments received 200 hours of blue sky towards sunset when the colours were in the shade, which may be taken as about equal to 50 hours of average skylight illumination. The light from a sky which is cloudy has very much the same composition as sunlight itself, as we have repeatedly proved. Supposing, however, we take it that the light was half due to blue sky and half to that of sunlight, this is equivalent to the pigments being exposed for 600 hours to light of the same composition as that of a blue light from the sky and 600 hours to light of the same average composition as sunlight. Now, for equal units of illumination skylight, as already stated, is almost exactly twice as rich in blue rays as is sunlight. Therefore, the 600 hours to which the pigments were exposed to degraded sunlight is equivalent to 300 hours of light of the quality of skylight. Hence we may take it that the pigments were exposed when the sun was not shining to 900 hours of light of the same quality as that coming from the blue sky, but inferior in illumination. We have next to take some measure of what this inferiority may be. Measures taken show that the light coming from the sky at the time of year when the exposures were made varies from $\frac{3}{4}$ths to $\frac{1}{10}$th, and sometimes less in brightness of that coming from an unclouded sky, the measurements being taken at the same time of day. If we assume that the average illumination of an overcast sky is $\frac{1}{3}$rd of that of a blue sky, we shall not be far wrong. Applying this factor, we find that the pigments were exposed for an equivalent of 300 hours of average bright blue sky beyond that to which they were exposed when the sun was shining. It may therefore be said that the pigments received a total illumination equivalent to 2,225 hours of average blue sky, which is made up of the 1,875 hours, the 50 hours, and the 300 hours. This of course is only an approximate estimate, owing to the very variable quantities dealt with, but still it will give an idea of the illumination by the blue rays which were effective in causing the fading.

Calculation of exposure in a South Kensington gallery to produce fading.

XXIII. We may now go a step further, and calculate approximately the amount of illumination which a picture hung in a gallery, such as those at South Kensington, would receive during the same period. No direct sunlight would be admitted, and therefore the illumination due to the direct light from the sun would be eliminated. Photometric measurements show that the blue light illuminating a picture in these galleries varies between $\frac{1}{40}$th and $\frac{1}{90}$th of that to which it (when no blinds are used for subduing the light) would be subjected if it were placed where our pigments were exposed and illuminated by the sky alone. Now when there is a blue sky the ratio is least, and we shall be safe in taking it as $\frac{1}{75}$th. For the 700 hours when the sun was shining we should therefore have an equivalent inside the gallery to about 9·3 hours of average blue sky. For the 1,200 hours of light from an overcast sky we may take the factor of $\frac{1}{40}$th both for the 600 hours of light which was of the quality of light from a blue sky and also of the light for the 600 hours which we supposed to be of the same quality as of sunlight, which, both together, we took to be equivalent to 300 hours of light from an unclouded blue sky. This would give an exposure equivalent to 7·5 hours of the average light from a blue sky, such as that to which the pigments were exposed, or in all 16·8 hours. This would make the exposure of a picture inside the gallery about $\frac{1}{130}$th of that given to the pigments during the same time. If the whole year was of the same daily average brightness as that between 15th May and the 15th August, the same effect would have been produced on the pigments located against the walls of one of these galleries in about 32 years. Seeing that the daily intensity and continuance of light is so enormously diminished in the autumn and winter we shall not be overstating facts when we say that it would have taken 100 years in the gallery in question to have arrived at the same degree of fading as to that to which the pigments had arrived by our sunlight experiments up to August 1886.

Calculation of exposure necessary to be given to gaslight to produce fading.

XXIV. We will now endeavour to make an approximate estimate of the time which would have been required had our experiments been conducted in light falling on the walls of the same gallery when lighted by gaslight or the electric glow lamps. General Festing has furnished us with the measurements taken by him with the Preece photometer of the illumination of the walls of some of the galleries so lighted.

The N.E. water colour room (gas) 1·81 candles at 1 foot off.

The S.E. water colour room (gas) 2·32 candles at 1 foot off.

The Jones Bequest Gallery (electric glow lamp) 1·72 candles at 1 foot off.

Raphael Gallery electric (arc) light 2·26 candles at 1 foot off.

Sheepshanks Gallery electric (arc) light 3·12 candles at 1 foot off.

The glow lamp light and the gaslight have very closely the same composition, and we may, therefore, take it that the mean illumination on the walls lighted by gaslight and electric incandescence lamps is equal to two candles at one foot off. The illumination of the same galleries by daylight has been measured, and the mean light for the whole year may be taken as about six candles at 1 foot off. In Part III. details of the candle value of the illumination for the brightest months in the year has been given. The illumination in the winter months is so small that this average may be taken. That is, the mean illumination by day is three times better than by night, but the blue rays in one unit of the illuminating value of light of gaslight are only $\frac{1}{10}$th on cloudy days to $\frac{1}{20}$th on days when the sky is clear of those contained in a unit day light. We may take $\frac{1}{15}$th as a probable proportion, and on this assumption the blue light illumination by the latter is about $\frac{1}{45}$th of that of the former. That is to say, that one hour's exposure to mean daylight is about equal to 45 hours of gaslight. We have already estimated that to produce the fading which took place in the colours between May and August in direct sunshine at least 100 years would have been required had the exposure been made in the gallery. Allowing for the duration of darkness, it would have taken at least 2,000 years continuous illumination to have produced the same result in gaslight or in the light from the electric glow lamps. With the arc electric light giving an illumination of 2½ candles at one foot off we calculate, on similar data, that the same result would have been obtained in not less than 200 years.

Exposure necessary to be given in a South Kensington gallery to produce final results obtained in sunlight.

XXV. Our final results were obtained after an exposure between May 1886 and March 1888, during which time there had been about 3,000 hours of sunshine in all, 2,100 of which we may take it fell on the colours. Making the same estimates as before, we find that this was equivalent to 8,800 hours of mean blue sky light. There would be left about 8,000 hours of light during which no sun was shining. Taking it as before, we should find that this was equal to 6,000 hours of subdued blue sky light, and when reduced to $\frac{1}{3}$rd, would be equivalent to 2,000 hours of mean bright blue sky light. This, with the sun light, would give a total of 10,800 hours of the blue sky light to which the pigments were exposed, or about 4·8 times the amount which they received between May and August 1866. To produce our final result therefore we should have had to expose them in the gallery for at least 480 years, and to the gas light continuously for 9,600 years. Had we exposed to the whole of the light coming from the southern sky alone, shielding the colours from direct sunlight, we should have had to extend our observations for four years, and if to a northern sky probably for nearer 10 years, since the mean brightness of the latter is considerably less than the former.

Final remarks on exposure necessary to produce fading.

XXVI. With these estimates before us, it is not surprising that we should have preferred to use an illumination which would give us results which we ourselves should be able to discuss. We may remark that a certain amount of impatience has been exhibited in some quarters at what to them appears the prolonged time which has elapsed since our experiments were commenced. We trust that the statement we have made regarding the approximate lengths of exposure which are required will show that experiments of this nature are not capable of being hurried, or, when partially completed, of being discussed except after weighing all causes which are operating. We must here enter a protest against the loose way in which comparative exposures in sun light and sky and subdued light are spoken of. For instance, the fact that colours have been exposed for so many hours sunshine as compared with so many hours of light from the sky has but little meaning or value (*a*) unless the total effective light during the whole period of both be measured, or (*b*) unless the exposure has been so prolonged that it is safe to resort to averages. We have carried out experiments in both directions and the one confirms the other. We may again emphatically repeat that experiment has shown that knowing the composition of the light used and intensity of its different components, and the effect which they produce on a pigment in a given time, it is only a matter of calculation to arrive at the time necessary to produce the same result with any other light whose composition is known. The details of the experiments on which the foregoing calculations are based have in part already been communicated to the Royal Society by one of us and Major-General Festing, F.R.S., and some of the remainder will be also communicated to that body, and others will be embodied in our second report.

PART II.

DESCRIPTION AND RESULT OF EXPERIMENTS WITH VARIOUS COLOURS.

I. In the following experiments the moist colours of one firm were employed. We have tried, as will be seen, the action of light on the single colours, and on mixtures of two or more colours. Sir J. D. Linton P.R.I., Mr. E. J. Poynter, R.A., and others kindly supplied us with an account and samples of the different mixtures they employed, and these were copied with as much accuracy as possible. Those mixtures were avoided in which a change would of necessity take place without the action of light owing to the known chemical composition of the colours. We have not confined ourselves solely to the above makers' colours, but have experimented with colours from other makers both dry, in pans, and in tubes. An account of these experiments we reserve for our next report, merely mentioning that the results so far do not greatly differ from those recorded below.

Colours employed in the experiments.

II. The paper which we have used is Whatman's, and in order that no variation of quality should occur in different experiments, we obtained at once sufficient for the whole investigation. This paper was examined and found to contain only a trace of thiosulphate and in every square foot nearly 1 grain of sizing matter. The amount of moisture present, as we shall show, is a matter of considerable importance, and obviously will vary with the condition of the surrounding atmosphere. We have found that the "hot pressed" paper is capable of absorbing from a moist atmosphere as much as 12·46 per cent. of its weight of water, the "not pressed" 12·20, and the rough 12·07 per cent. This absorption of moisture goes on slowly, even when the paper is fully exposed to a saturated air. Twenty-four hours elapse before the paper is perfectly saturated..

Paper employed.

III. The published experiments on the action of light on colours are few, and have been made under undefined conditions. We therefore commenced our investigation by taking a very large number of the colours which are ordinarily used and exposing them to conditions rigorously determined. These conditions were selected so as to give us definite information as to the nature of the changes, if any, which occurred. The colours to be tested were applied, by a practised hand, to the paper in a series of washes, the first wash extending over the whole sheet, the second one leaving a strip 1 in. wide and the length of the paper untouched. The following figure represents one of these strips. In most cases as many as eight washes were applied, giving thus a complete series of 8 tints. In the following experiments strips 2 ins. wide and 8 ins. long, having all the tints upon them, were used. Fig. X. represents one of these strips.

Mode of preparing the coloured papers.

Fig. X.

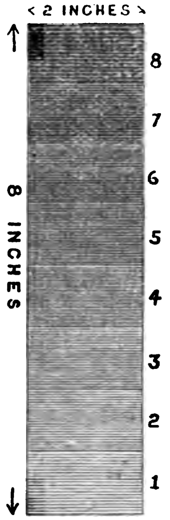
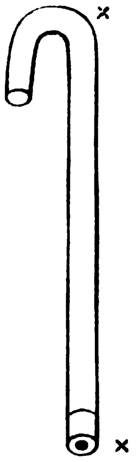


Fig. XI



Experiments in day and sun light.

IV. In the first series of experiments the colours were subjected to conditions similar to those to which pictures are subjected, but to an exaggerated extent. The experiments were carried out as follows: two strips of the coloured paper cut from the same sheet were carefully introduced into a glass tube ¾ in. in diameter and 2 ft. long, open at both ends, the upper end being bent over to prevent the entrance of wet and dirt. The tubes were hung vertically out of doors against a wall facing nearly south, where all the sunshine until after 3.30 could fall upon them. A piece of American cloth was carefully bound round one half of the tube, thus effectually protecting one strip of the paper from light. The two pieces of identically tinted coloured-paper were therefore under exactly the same conditions in all respects, except that one was exposed to light, and the other was in the dark.

In these experiments the colours were exposed to the action of light, air, and moisture, as are pictures, only to a greater extent. They had to bear the action of direct sunlight, the air circulated through the tube, and the paper was in contact with the outer air. This free circulation of the air also prevented, as already indicated, any very appreciable rise in temperature in the tube. These papers were exposed from May 1886 till March 1888. They were observed for the first time on the 14th of August 1886, again in December 1886, and in July and in November 1887, and finally in March 1888. The results of the first and last examination are given in Table I.

TABLE I.

OPEN TUBE.

Effect of light on colours exposed in open tubes.

Name of Colour.	August 14th, 1886.	March, 1888.	Remarks.*
Carmine	Gone	Gone	—
Crimson Lake	Gone to 7	Gone	—
Scarlet Lake	Pink gone, Vermilion left.	Gone	—
Vermilion	No change	Gone black	—
Rose Madder	No change	Faded to 4, and bluer.	—
Madder Lake	No change	Sl. faded	—
Indian Red	No change	No change	—
Venetian Red	No change	No change	—
Brown Madder	Changed to 4	Faded to 3	—
Burnt Sienna	No change	No change	—
Gamboge	Faded to 2	Faded to 7	—
Aureolin	No change	Faded to 4	—
Chrome Yellow	No change	No change	—
Cadmium Yellow	No change	Gone	—
Yellow Ochre	No change	V. sl. faded	—
Lemon Yellow	No change	No change	—
Naples Yellow	Faded to 5	Gone	—
Indian Yellow	Faded to 2	Faded to 6	—
Raw Sienna	No change	No change	—
Emerald Green	No change	Sl. brown	—
Terra Verte	No change	No change	—
Chrom. Oxide	No change	No change	—
Olive Green	Blue gone	Gone brownish pink.	—
Antwerp Blue	Paler	Gone green	Blue revived.
Prussian Blue	A little lighter, no green.	No change	—
Indigo Blue	Gone to 4, all lighter.	Faded to 8	—
Cobalt Blue	No change	No change	—
French Blue	No change	No change	—
Ultramarine Ash	No change	No change	—
Leitches (cyanin) Blue	V. sl. faded	No experiment	—
Permanent Blue	No change	Faded to 4	—
Paynes Grey	Gone red to 7	Gone	—
Violet Carmine	Red nearly gone.	Bleached to 6	—
Purple Carmine	Red nearly gone.	Bleached to 6	—
Purple Madder	Faded to 7	Faded to 8	—
Sepia	Faded to 1, all lighter.	Faded to 8	—
Vandyke Brown	Faded to 4	Gone	—
Burnt Umber	No change	V. sl. faded	—

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* The effects noted in this column took place after the pigments had been about one month in the dark.

NOTE.—Sl. means slightly; V. sl. means very slightly; No. 1 is the faintest tint.

Name of Colour.	August 14th, 1886.	March, 1888.	Remarks.
Brown Pink	Gone to 3	Faded to 7	—
Indian Yellow and Rose Madder	Gone pink to 6, yellow going in all.	Gone pink	—
Rose Madder and Raw Sienna	No change	V. sl. yellowed to 5.	—
Raw Sienna and Venetian Red	No change	No change	—
Venetian Red, Madder Red, Indian Yellow.	Redder in all	Sl. faded, gone pink.	—
Vermilion and Chrome Yellow	No change	Darkened	—
Indian Red and Rose Madder	No change	No experiment	—
Indian Yellow and Rose Madder	Part faded, yellow gone to 3.	Gone pink	—
Burnt Sienna and Naples Yellow	Browner	V. sl. faded	—
Indigo, Indian Yellow, Raw and Burnt Sienna.	Gone reddish in all.	Gone red	—
Indigo and Gamboge	Gamboge going in all.	Faded to 6	—
Prussian Blue and Gamboge	Yellow going	Gone blue to 7	—
Burnt Sienna and Antwerp Blue	Sl. redder	Gone sl. brown	Blue revived.
Raw Sienna and Antwerp Blue	Sl. redder	No change	—
Prussian Blue, Raw and Burnt Sienna.	Blue gone	Brown	Blue revived 1 to 3.
Indigo and Vandyke Brown	Vandyke brown going, all gone as far as 2.	Faded to 5	—
Prussian Blue and Burnt Sienna	Blue gone	Gone brown	Blue revived.
Prussian Blue and Raw Sienna	Browner	Gone brown	—
Indigo and Raw Sienna	Reddish	Gone yellow to 5.	—
Indigo and Burnt Sienna	Sl. Browner	Gone brown	—
Leitches Blue and Burnt Sienna	Browner	Gone brown	Blue revived 1 to 5.
Leitches Blue and Raw Sienna	Browner	Gone brown	—
Indigo, Raw and Burnt Sienna	Browner	Gone red	—
Prussian Blue and Vandyke Brown	Blue and fading to 3, Vandyke brown gone in all.	Blue gone and a little brown left.	Blue revived.
Indigo and Venetian Red	Redder	Gone red	—
Prussian Blue and Indian Red	Gone red in all.	Gone red	Blue revived.
Cobalt and Indian Red	No change	No change	—
Prussian Blue and Venetian Red	Gone red in all.	- - -	—
Antwerp Blue and Rose Madder	Gone pinkish	Gone pink	—
Prussian Blue and Crimson Lake	Red all gone, blue lighter.	Gone blue	—
Antwerp Blue and Crimson Lake	Red all gone	Gone blue	—
Indigo, Venetian Red, Yellow Ochre	Redder	Gone reddish	—
Prussian Blue, Yellow Ochre, Venetian Red.	Redder	Gone red	—
Indigo, Raw and Burnt Sienna, and Indian Yellow.	Browner	Gone brown	—
Indigo and Indian Red	Sl. redder	Red to 7	—

Note.—Where Nos. are given in this and in following tables the higher the number the deeper the tint referred to. Thus, in these experiments, No. 1 is the faintest tint and No. 8 the deepest tint.

Note.—Sl. means slightly; V. sl. means very slightly; No. 1 is the faintest tint.

In the fourth column we have noted the curious change which often occurs with Prussian blue, namely, the return of the blue colour if the faded paper be placed for some time in comparative darkness. This very interesting change will be discussed in detail in the second part of our report.

In some cases the colour entirely disappeared, in carmine for instance. In the majority of cases only a part of the colour disappeared, the thinner washes fading out; but the following pigments were able to withstand this most trying ordeal, and remained unchanged. They are: Indian red, Venetian red, burnt sienna, chrome yellow, lemon yellow, raw sienna, terra verte, chromium oxide, Prussian blue, cobalt blue, French blue, and ultramarine ash. The following mixtures also underwent no change: raw sienna and Venetian red, raw sienna and Antwerp blue, cobalt and Indian red. The table will show that other colours and mixtures under these extreme conditions are only very slightly acted on, and that no actually sharp line can be drawn in these cases.

Order of instability of colours exposed in an ordinary atmosphere.

V. Table II. shows approximately the order of instability of the single colours in open tubes which we have tried, beginning with the most fugitive.

TABLE II.

Carmine.
Crimson Lake.
Purple Madder.
Scarlet Lake.
Paynes Grey.
Naples Yellow.
Olive Green.
Indigo.
Brown Madder.
Gamboge.
Vandyke Brown.
Brown Pink.
Indian Yellow.
Cadmium Yellow.
Leitches Blue.
Violet Carmine.
Purple Carmine.
Sepia.
Aureolin.
Rose Madder.
Permanent Blue.
Antwerp Blue.
Madder Lake.
Vermilion.
Emerald Green.
Burnt Umber.

Yellow Ochre.
Indian Red.
Venetian Red.
Burnt Sienna.
Chrome Yellow.
Lemon Yellow.
Raw Sienna.
Terra Verte.
Chromium Oxide.
Prussian Blue.
Cobalt.
French Blue.
Ultramarine Ash.

Show no change.

Of these 39 single colours 12 were not acted upon at all by light, and two others were only after this long exposure to direct sunlight very slightly faded.

All of these, except Prussian blue, are purely mineral colours. Of the 34 mixtures tried only three remained from first till last unchanged, but six mixtures containing Prussian blue, although at first altered, on placing in the dark for six weeks more or less returned to their original colour.

It is of considerable interest to note that in the cases in which any change occurred it had commenced before our record made in December 1886, though not in all cases before August 14th.

Exposure of colours to light in dry air.

VI. In another series of experiments, carried out at the same time with mostly the same pigments, the atmosphere to which they were exposed was free from all moisture. The glass tube was first heated, allowed sufficiently to cool, the dried tinted paper carefully introduced, and the glass tube hermetically sealed. As before, two similarly coloured strips of paper were introduced into each tube, one was protected from light, the other exposed fully to it. Table III. gives the results obtained. Thirty-eight experiments were made with single colours; but under this altered condition, 22 instead of 12 were found to be permanent, principally those colours which in the former experiments were only very slightly faded. In two cases the colour in the open tube was not acted on, while that in the dry tube was; these cases are brown madder and Prussian blue. The colours which were unchanged in dry air, but were acted on in ordinary air are madder lake, cadmium yellow, Naples yellow, emerald green, olive green, Paynes grey, sepia, and burnt umber. Again, with the single exception of madder lake, all the above which were not acted on in dry air are mineral colours.

TABLE III.

Name of Colour.	Dry Air.
Carmine - - - - -	Faded to 7.
Crimson Lake - - -	Gone to 5.
Scarlet Lake - - - - -	Faded and darkened.
Vermilion - - - -	Gone black.
Rose Madder - - - -	No change.
Madder Lake - - - -	No change.
Indian Red - - - -	No change.
Venetian Red - - - -	No change.
Brown Madder - - - -	Faded to 4.
Burnt Sienna - - - -	No change.
Gamboge - - - -	Faded to 3.

Name of Colour.	Dry Air.
Aureolin	No change.
Chrome Yellow	No change.
Cadmium Yellow	No change.
Yellow Ochre	No change.
Naples Yellow	No change.
Indian Yellow	Faded to 4.
Raw Sienna	No change.
Emerald Green	No change.
Terra Verte	No change.
Chrom. Oxide	No change.
Olive Green	No change.
Antwerp Blue	Faded to 3.
Prussian Blue	Faded to 5.
Indigo Blue	Faded to 7.
Cobalt Blue	No change.
French Blue	Nochange.
Ultramarine Ash	No change.
Leitches Blue	Faded to 5.
Permanent Blue	No change.
Paynes Grey	No change.
Violet Carmine	Faded and brown.
Purple Carmine	Faded.
Purple Madder	Faded to 4.
Sepia	No change.
Vandyke Brown	V. sl. faded.
Burnt Umber	No change.
Brown Pink	Faded to 4.

NOTE.—Sl. means slightly; V. sl. means very slightly; No. 1 is the faintest tint.

Exposure of colours to light in moist air.

VII. In the next series of experiments the colours were exposed to air fully saturated with moisture. The paper was saturated with moisture, and was sealed up in tubes containing moist air. Thirty-seven experiments with single colours were made; the results are given in Table IV. Only 10 colours withstood the action of light under this condition: these were Indian red, Venetian red, burnt sienna, yellow ochre, raw sienna, emerald green, terra verte, chromium oxide, cobalt, and ultramarine ash. No vegetable colour is in this list, and both Prussian blue and Antwerp blue were entirely destroyed. Twenty-nine mixtures were also tested in a similar way, and only two remained unchanged; these were raw sienna and Venetian red, and cobalt and Indian red.

TABLE IV.

Name of Colour.	Moist Air.
Carmine	Gone.
Crimson Lake	Gone.
Scarlet Lake	Faded and blackened.
Vermilion	Gone black.
Rose Madder	Faded to 6.
Madder Lake	Faded to 5.
Indian Red	No change.
Venetian Red	No change.
Brown Madder	Faded to 4.
Burnt Sienna	No change.
Gamboge	Faded to 3.
Aureolin	Faded to 6.
Cadmium Yellow	Faded to 3.
Yellow Ochre	No change.
Lemon Yellow	Faded to 4.
Naples Yellow	Faded to 8.
Indian Yellow	Faded to 6.
Raw Sienna	No change.
Emerald Green	No change.
Terra Verte	No change.
Chrom. Oxide	No change.
Olive Green	Gone brown.
Antwerp Blue	Gone.
Prussian Blue	Gone.
Indigo Blue	Faded to 8.
Cobalt Blue	No change.
French Blue	Bleached to 2.
Ultramarine	No change.
Permanent Blue	Faded to 5.
Paynes Grey	Faded to 6.
Violet Carmine	Gone brown.
Purple Carmine	Gone brown.
Purple Madder	Gone.
Sepia	Faded to 7.
Vandyke Brown	Faded to 5.
Burnt Umber	No change.
Brown Pink	Faded to 7.
Indian Yellow and Rose Madder	Pink.
Rose Madder and Raw Sienna	V. sl. faded.
Raw Sienna and Venetian Red	No change.
Venetian Red, Madder Red, Indian Yellow	Gone red.
Vermilion and Chrome Yellow	Gone black.
Indian Red, Rose Madder	Gone pink.
Burnt Sienna and Naples Yellow	V. sl. faded.
Indigo, Indian Yellow, Raw and Burnt Sienna	Gone red.
Indigo and Gamboge	Faded to 5.

Name of Colour.	Moist Air.
Burnt Sienna and Antwerp Blue - -	Gone brown.
Raw Sienna and Antwerp Blue - -	Gone brown.
Prussian Blue, Raw and Burnt Sienna, and Indian Yellow.	Gone brown.
Prussian Blue and Burnt Sienna - -	Gone red.
Indigo and Vandyke Brown - - -	Gone blue.
Prussian Blue and Burnt Sienna - -	Gone red.
Prussian Blue and Raw Sienna - -	Gone brown.
Indigo and Raw Sienna - - -	Gone red.
Indigo and Burnt Sienna - - -	Gone brown.
Leitches Blue and Burnt Sienna - -	Gone brown.
Leitches Blue and Raw Sienna - -	Gone brown.
Indigo, Raw and Burnt Sienna - -	Gone red.
Indigo and Venetian Red - -	Gone red.
Cobalt and Indian Red - - -	No change.
Indigo and Indian Red - - -	Gone red.
Prussian Blue and Venetian Red - -	Gone red.
Antwerp Blue and Rose Madder - -	Gone pink.
Prussian Blue and Crimson Lake - -	Gone.
Antwerp Blue and Crimson Lake - -	Gone blue.
Indigo, Venetian Red, Yellow Ochre -	Gone red.

NOTE.—Sl. means slightly; V. sl. means very slightly; No. 1 is the faintest tint.

Exposure of colours to light in the presence of hydrogen.

VII. To eliminate the effect of oxygen, a further series of experiments were made in which the colour was exposed in an atmosphere of moist hydrogen gas. Thirty-six experiments were made with single colours, and of these no less than 22 remained unchanged; even carmine and crimson lake did not alter, neither did madder lake, Indian red, Venetian red, brown madder, burnt sienna, chrome yellow, yellow ochre, raw sienna, terra verte, chromium oxide, olive green, indigo, cobalt, French blue, ultramarine ash, permanent blue, Paynes grey, sepia, Vandyke brown, and burnt umber. The results are given in Table V.

TABLE V.

Name of Colour.	Moist Hydrogen.
Carmine - - - - -	No change.
Crimson Lake - - - -	No change.
Scarlet Lake - - - -	No change.
Vermilion - - - - -	Gone black.
Madder Lake - - - - -	No change.
Indian Red - - - -	No change.

Name of Colour.	Moist Hydrogen.
Venetian Red - - - -	No change.
Brown Madder - - - -	No change.
Burnt Sienna - - - -	No change.
Gamboge - - - -	Sl. faded.
Aureolin - - - -	Faded.
Chrome Yellow - - -	No change.
Cadmium Yellow - - -	Sl. faded.
Yellow Ochre - - - -	No change.
Naples Yellow - - -	Faded.
Indian Yellow - - - -	Faded.
Raw Sienna - - - -	No change.
Emerald Green - - - -	Black and pink.
Terra Verte - - - -	No change.
Chrom. Oxide - - - -	No change.
Olive Green - - - -	Gone brown.
Antwerp Blue - - - -	Gone.
Prussian Blue - - - -	Gone.
Indigo Blue - - - -	No change.
Cobalt Blue - - - -	No change.
French Blue - - - -	No change.
Ultramarine - - - -	No change.
Leitches Blue - - - -	Faded to 6.
Permanent Blue - - -	No change.
Paynes Grey - - - -	No change.
Violet Carmine - - -	Black.
Purple Madder - - -	Faded to 3.
Sepia - - - - -	No change.
Vandyke Brown - - -	No change.
Burnt Umber - - - -	No change.
Brown Pink - - - -	Gone yellow.

NOTE.—Sl. means slightly; V. sl. means very slightly; No. 1 is the faintest tint.

Exposure of colours to light in vacuo.

VIII. Another series of experiments were made, and in these the air and moisture were, as far as possible, removed from the tubes containing the coloured papers; the papers were carefully dried, and the air pumped by a Sprengel pump out of the tube, which was then hermetically sealed. Thirty-nine experiments with single colours were made, and it will be seen by Table VI. that hardly any colour under this condition is acted on by light. Violet carmine and purple carmine slightly darkened; Prussian blue and purple madder and sepia slightly bleached; but in all cases the action was very feeble. Twenty-four experiments were made with mixed colours, and the results are of much interest and importance. The mixtures containing Prussian blue changed, the other colour becoming dominant. Vermilion also blackened. With other mixtures hardly any change occurred.

TABLE VI.

Name of Colour.	Vacuum.
Carmine	No change.
Crimson Lake	No change.
Scarlet Lake	No change.
Vermilion	Gone black.
Rose Madder	No change.
Madder Lake	No change.
Indian Red	No change.
Venetian Red	No change.
Brown Madder	No change.
Burnt Sienna	No change.
Gamboge	No change.
Aureolin	No change.
Chrome Yellow	No change.
Cadmium Yellow	No change.
Yellow Ochre	No change.
Lemon Yellow	No change.
Naples Yellow	No change.
Indian Yellow	No change.
Raw Sienna	Sl. darkened.
Emerald Green	No change.
Terra Verte	No change.
Chrom. Oxide	No change.
Olive Green	No change.
Antwerp Blue	No change.
Prussian Blue	V. sl. faded.
Indigo Blue	No change.
Cobalt Blue	No change.
French Blue	No change.
Ultramarine Ash	No change.
Leitches Blue.	No change.
Permanent Blue.	No change.
Paynes Grey.	No change.
Violet Carmine	Sl. darkened.
Purple Carmine	Sl. darkened.
Purple Madder	V. sl. gone.
Sepia	Sl. faded to 6.
Vandyke Brown	No change.
Burnt Umber	No change.
Brown Pink	No change.
Indian Yellow and Rose Madder	No change.
Rose Madder and Raw Sienna	No change.
Raw Sienna and Venetian Red	No change.
Vermilion and Chrome Yellow	More yellow.
Burnt Sienna and Naples Yellow	V. sl. faded.
Indigo, Indian Yellow, Raw and Burnt Sienna	No change.
Indigo and Gamboge	Gone blue.
Prussian Blue and Gamboge	Gone green.
Burnt Sienna and Antwerp Blue	Gone red.

Name of Colour.	Vacuum.
Raw Sienna and Antwerp Blue - - -	Gone brown.
Prussian Blue, Raw and Burnt Sienna, and Indian Yellow.	Gone brown.
Prussian Blue and Burnt Sienna - -	Gone brown.
Indigo and Vandyke Brown - - -	Faded.
Prussian Blue and Burnt Sienna - -	Gone brown.
Prussian Blue and Raw Sienna - -	Gone red.
Indigo and Raw Sienna - - -	No change.
Indigo and Burnt Sienna - - -	No change.
Indigo, Raw and Burnt Sienna - -	No change.
Prussian Blue and Vandyke Brown - -	Gone brown.
Indigo and Venetian Red - - -	No change.
Prussian Blue and Indian Red - -	Gone red.
Indigo and Indian Red - - -	No change.
Prussian Blue and Crimson Lake - -	Gone pink.
Antwerp Blue and Crimson Lake - -	Gone pink.
Indigo, Venetian Red, Yellow Ochre - -	No change.
Prussian Blue, Yellow Ochre, Venetian Red -	Gone red.

NOTE.—Sl. means slightly; V. sl. means very slightly; No. 1 is the faintest tint.

Summation of results.

IX. The action of the surrounding medium on colours exposed to light is strikingly shown by the above experiments with moist air, dry air, and a vacuum, and in order to show at a glance the different effects produced, we append Table VII., in which we have grouped the colours thus acted on under the three heads of No change, Altered, and Destroyed. Under the heading of Altered, are included changes ranging from a very small destruction of colour to a very considerable one. Of course such a classification can only be approximate.

TABLE VII.

SINGLE COLOURS.

Moist Air.	Dry Air.	Vacuum.
No Change.	No Change.	No Change.
Indian red.	Indian red.	Indian red.
Venetian red.	Venetian red.	Venetian red.
Burnt sienna.	Rose madder.	Carmine.
Yellow ochre.	Madder lake.	Crimson lake.
Raw sienna.	Aureolin.	Scarlet lake.
Emerald green.	Chrome yellow.	Rose madder.
Terra verte.	Cadmium yellow.	Madder lake.
Chromium oxide.	Yellow ochre.	Brown madder.
Cobalt.	Naples yellow.	Burnt sienna.
Ultramarine ash.	Raw sienna.	Gamboge.

Moist Air.	Dry Air.	Vacuum.
	No change.	No change.
	Emerald green. Terra verte. Chromium oxide. Olive green. Cobalt. French blue. Ultramarine ash. Permanent blue. Paynes grey. Sepia. Burnt umber. Burnt sienna.	Aureolin. Chrome yellow. Cadmium yellow. Yellow ochre. Lemon yellow. Naples yellow. Indian yellow. Emerald green. Terra verte. Chromium oxide. Olive green. Antwerp blue. Indigo. Cobalt. French blue. Ultramarine ash. Vandyke brown. Burnt umber. Brown pink.
Altered.	Altered.	Altered.
Scarlet lake. Vermilion (black). Rose madder. Madder lake. Brown madder. Gamboge (very slightly). Aureolin. Cadmium yellow. Lemon yellow. Naples yellow. Indian yellow. Olive green (brown). Indigo. French blue. Permanent blue. Paynes grey. Violet carmine (brown). Purple carmine (brown). Purple madder. Sepia. Burnt umber (very slight). Brown pink. Vandyke brown.	Carmine. Scarlet lake. Vermilion (black). Brown madder. Gamboge. Indian yellow. Antwerp blue. Prussian blue. Indigo. Leitches blue. Violet carmine. Purple carmine. Purple madder. Vandyke brown (very slight). Brown pink.	Raw sienna (slightly darkened). Prussian blue (slightly darkened). Violet carmine (darker). Purple carmine (darker). Purple madder (very slightly faded). Sepia. Vermilion (blackened
Destroyed.	Destroyed.	Destroyed
Carmine. Crimson lake. Antwerp blue. Prussian blue.	None.	None.

Effect of Ox gall.

X. To determine whether a mixture of ox gall would influence the results, the following colours were mixed with that substance and tested in the same way and under the same conditions as the colours above had been tested. In no case did we find that the addition of the ox gall altered the result:—

Scarlet lake.
Rose madder.
Indian red.
Rose madder and raw sienna.
Indian yellow.
Indian yellow and rose madder.
Indian yellow, raw and burnt sienna.
Indigo and gamboge.
Indigo and raw sienna.
Indigo and burnt sienna.
Prussian blue.
Indigo.
Indigo and Venetian red.
Indigo, Venetian red, and yellow ochre.

Experiments with the arc electric light.

XI. In selecting the colours to be exposed to the electric light we have chiefly taken those most easily acted on. These were exposed, some in a frame with a glass in front, others under the most favourable conditions for fading, viz., in sealed tube with moist air to the full action of the electric light for about 84 hours. The light falling on these colours is estimated as having an illuminating value of 2,000 candles at a foot off.

Under these conditions the only single colours in the frame which underwent change were crimson lake (bleached and more red), and carmine (bleached and more red). Antwerp blue, Prussian blue, Naples yellow, brown pink, purple madder, rose madder, Vandyke brown, sepia, vermilion, Venetian red, Indian yellow, gamboge, indigo, Leitches blue underwent no change. With mixtures, Prussian blue yellow ochre and Vandyke brown, Prussian blue and raw and burnt sienna, and Prussian blue and burnt sienna all became slightly browner. Indigo and burnt sienna, indigo and gamboge, indigo and Indian red, Prussian blue and gamboge, Prussian blue and purple carmine, Prussian blue and Vandyke brown, Prussian blue and Indian red, Antwerp blue and raw sienna, rose madder and raw sienna, chrome yellow and vermilion, Venetian red and raw sienna underwent no change. In the tubes with moist air, carmine and Naples yellow very slightly altered, and crimson lake altered more. The following colours underwent no change: rose madder, vermilion, madder lake, gamboge, Indian yellow, Prussian blue, Antwerp blue, indigo, Leitches blue, Vandyke brown, brown pink sepia; neither did the mixtures of Prussian blue and Indian red, Prussian blue and gamboge, indigo and burnt sienna, indigo and Indian red. From the nature of these experiments they could not be carried on for an indefinite length of time.

Experiment with heat but without light.

XII. To determine whether heat, without light, would have any effect, the strips of the following colours, cut from the same sheets as those used in the previous experiments, were sealed up with moist air in glass tubes and heated for seven hours a day for three weeks in boiling water, all light being excluded.

Indian yellow changed very decidedly, a mixture of Prussian blue and gamboge went brown, also a mixture of Prussian blue and burnt sienna and Prussian blue and raw sienna, Antwerp blue, Leitches blue and permanent blue all bleached. In a second experiment the permanent blue did not change. Indigo and Venetian red also bleached very slightly and became more red in colour, whereas carmine, crimson lake, vermilion, Venetian red, Prussian blue, indigo, sepia, and brown pink underwent no change. Two tubes with rose madder were used, one of them bleached very slightly, the other not at all.

Action of the products of the combustion of gas on pigments.

XIII. This part of our investigation has, at present, only reached its first stage, and will be more fully considered in the second part of our report. The results already obtained are, however, of interest, and may be briefly stated. An ordinary gas jet, burning two cubic feet per hour, was kept burning day and night for three weeks in a cupboard 6 ft. 6 ins. long, 2 ft. 6 ins. wide, 5 ft. 6 ins. high. At the top of the cupboard was fastened a board on which strips of the following colours were pinned: Indian red, madder red, rose madder, carmine, crimson lake, Venetian red, scarlet lake, madder lake, vermilion, burnt sienna, Indian yellow, burnt umber, gamboge, Naples yellow, chrome yellow, cadmium yellow, aureolin, chromium oxide, emerald green, Prussian blue, cobalt, indigo, Paynes grey, Leitches blue, Antwerp blue, French blue, purple carmine, sepia, indigo and gamboge, indigo and Venetian red and yellow ochre; Prussian blue and raw sienna, Prussian blue and Venetian red, Prussian blue and crimson lake. The temperature to which these colours were exposed was 82° Fahr. Of course no moisture deposited upon them, but the window to the cupboard was bedewed; under these circumstances hardly any change occurred. Crimson lake was slightly bleached, madder lake became a little redder, and Antwerp blue and Prussian blue a shade greener. The changes which probably occur under slightly different conditions we shall treat of hereafter.

Experiments with body colours.

XIV. We have already pointed out the action which must occur on diluting any colours with a solid white medium such as Chinese white. But few comparative experiments have yet been made. Mixtures of rose madder and Indian yellow, and of Prussian blue and gamboge, when mixed with Chinese white faded more rapidly than without it, and a mixture of Prussian blue and crimson lake are strikingly acted on, for without Chinese white the mixture becomes blue, but if mixed with Chinese white, it becomes of a bright pink colour. The fading of Prussian blue appears to be brought about by the addition of Chinese white. The following mixtures exposed in a frame at a window receiving about half the day's sun from May 19th, 1887, till January 18th, 1888, did not show any marked difference although mixed with Chinese white. Indigo and burnt sienna, vermilion and chrome yellow, Antwerp blue and burnt sienna, purple madder and burnt sienna, rose madder and Indian yellow. The following single pigments were also tried but the addition of Chinese white did not appear to hasten their fading. The vermilion mixed with the Chinese white darkened a shade more than without it, and the fading of Prussian blue was increased by it.

Carmine.
Rose madder.
Crimson lake.
Vermilion.
Gamboge.
Indian yellow.
Vandyke brown.
Sepia.
Brown pink.
Purple madder.
Violet carmine.
Paynes grey.
Antwerp blue.
Prussian blue.
Indigo.
Burnt Sienna.

Strips of the following colours with and without Chinese white were sealed up in tubes with moist air and exposed to all the sunlight there was from May 20th till July 29th 1887. Rose madder, Paynes grey, sepia, vermilion, violet, carmine, crimson lake and Prussian blue, indigo and burnt sienna, and Prussian blue and burnt sienna. The only case in which the addition of the Chinese white made a perceptible difference was in the mixture of Prussian blue and crimson lake. The change was the same as above described.

Experiments with coloured glasses.

XV. The following single and mixed colours chosen on account of their instability (see Table II.) were exposed from May 1887 till January 1888, under such conditions as to receive about one half the skylight and half the possible amount of sunlight. The composition of the light transmitted through the red, green, and blue glasses used, has been already stated, Fig. VII. Taking first the action of the red light, only four single colours were acted upon but slightly by it, these were indigo, Leitches blue, crimson lake, and Prussian blue. With the mixed colours, the only cases in which action occurred were those in which indigo was present they faded, for the indigo was destroyed. Under the green glass five single colours and two mixtures showed alteration, viz., Leitches blue, Paynes grey, crimson lake, Vandyke brown, carmine, Prussian blue, and crimson lake, also Prussian blue with raw sienna. All these changes occurring under the red and green glasses were very slight. A reference to the diagrams which give the optical composition of the different colours will show that these particular colours absorb in the red and in the green, hence their fading. We come now to the blue glass, and it will be seen that the amount of fading in this case is nearly, though not quite so much, as under the white glass, the difference being due to the opacity of blue glass even for blue rays. (See Fig. VII.) All the colours under the blue and white glass (burnt sienna excepted) were acted on. This clearly shows that it is the blue end of the spectrum which is active in producing the fading of colours.

——	White.	Blue.	Green.	Red.
Purple Madder	Faded to 2	Faded to 1	—	—
Antwerp Blue	No experiment	Faded	—	—
Leitches Blue	Sl. faded	Sl. faded	Darkened	Darkened.
Violet Carmine	Faded to 1	Faded to 1	—	—
Paynes Grey	Faded to 1	Bluer	Blue	—
Indigo	No experiment	Faded to 1	—	Sl. faded.
Prussian Blue	No experiment	Sl. faded	—	V. sl. faded.
Rose Madder (2 experiments.)	Sl. bleached	Sl. faded	—	—
Brown Pink	No experiment	Faded to 3	—	—
Crimson Lake	No experiment	Faded	Sl. faded	Sl. faded.
Vandyke Brown	No experiment	Faded to 1	Sl. faded	—
Vermilion	Darkened	V. Sl. darkened	—	—
Carmine	No experiment	Faded to 3	Sl. faded	—
Gamboge	No experiment	Faded to 1	—	—
Indian Yellow	No experiment	No change	—	—
Sepia	Become lighter	Become lighter	—	—
Burnt Sienna	No change	No change	—	—

Mixtures.

Indigo and Burnt Sienna, 2 experiments.	Bleached to 2	Bleached to 1	—	—
Indigo and Venetian Red.	Bleached	Red to 1	—	Sl. red.
Indigo and Raw Sienna.	No experiment	Gone red	—	Fading.
Indigo and Vandyke Brown.	Lighter	Lighter	—	Browner.

—	White.	Blue.	Green.	Red.
Indigo and Indian Red.	Very sl. faded	—	—	—
Indigo and Gamboge	Gone blue -	Gone blue -	—	—
Prussian Blue and Crimson Lake.	Gone bluish green.	Gone to a neutral tint.	Pinkish blue -	—
Prussian Blue and Gamboge.	Much gone, little blue in No 1.	Same as under white.	—	—
Prussian Blue and Burnt Sienna.	Brown, Prussian blue quite gone in 1 and 2.	Same as under white.	—	—
Prussian Blue and Raw Sienna.	No experiment	Faded to 1 -	Sl. faded -	—
Antwerp Blue, Rose Madder, and Indian Yellow.	Become bluer	Become bluer	—	—
Prussian Blue and Purple Carmine.	Quite green -	Green -	—	—
Antwerp Blue and Burnt Sienna.	Burnt sienna only left.	Burnt sienna left.	—	—
Indian Yellow and Rose Madder.	Rose madder left.	Became pink	—	—
Chrome Yellow and Vermilion.	Blackened -	Sl. faded -	—	—

Colours mixed with Chinese White.

Prussian Blue and Raw Sienna.	No experiment	Faded to 2 -	—	—
Rose Madder and Indian Yellow.	No experiment	Rose madder left.	—	—
Antwerp Blue and Burnt Sienna.	Brown to 3 -	Brown to 3 -	—	—
Indigo and Raw Sienna.	No experiment	Bleached -	—	—
Indigo and Burnt Sienna.	Burnt Sienna left.	Sl. red -	—	—
Indigo - -	No change -	No. change -	—	—
Antwerp Blue -	No experiment	Bleached -	—	—
Prussian Blue -	No experiment	Bleached -	—	—
Purple Madder -	Bleached -	Bleached -	—	—
Burnt Sienna -	No change -	No change -	—	—
Gamboge - -	No experiment	Sl. bleached -	—	—
Indian Yellow -	No experiment	Sl. bleached -	—	—
Vandyke Brown -	No experiment	Bleached -	—	—
Brown Pink - -	No experiment	Bleached to 3	—	—
Crimson Lake -	No experiment	Bleached to 3	—	Sl. faded.
Carmine - -	No experiment	Bleached to 3	—	—
Vermilion - -	Blackened -	Blackened under 1 and 2.	—	—
Rose Madder -	Sl. bleached -	V. sl. bleached	—	—
Violet Carmine -	Bleached to No. 1 and darkened to 2 and 3.	Same as under white glass.	—	—
Paynes Grey -	Bleached to 1	Become bluer	Become bluer	—
Sepia - - -	Lighter -	Lighter -	—	—
Prussian Blue and Burnt Sienna.	Prussian blue gone in 1 and 2.	Same as under white glass.	—	—
Prussian Blue and Crimson Lake.	Became of bluish green.	Became of a neutral tint.	Pinkish blue -	—

NOTE.—Sl. means slightly; V. sl. means very slightly; No. 1 is the faintest tint.

Effect on colours exposed to the light of a room.

XVI. In addition to the severe tests, both with regard to surrounding atmosphere and amount of light, to which we subjected the different colours, it was clearly of interest and importance to have similar specimens of colours subjected to milder treatment, and under conditions approximating to those to which pictures are usually subjected. We have therefore taken strips of our tinted papers and exposed them in a picture frame under a glass, so that one half of each paper was exposed to light, and the other half, bent back, was entirely shielded from the light. The back and glass were carefully pasted into the frame so as to exclude dust, as would be done with a picture, and the frame was then exposed in a room to very bright light, but not to direct sunlight. During a part of the time the frame was hung up against a window, during the remaining time it was at a little distance from the window. The frame was first exposed to the light on August 4th, 1886, and was opened, and the colours examined on May 6th, 1888.

The following colours were in the frame :—

Antwerp blue.
Prussian blue.
Leitches blue.
Indigo.
Gamboge.
Brown pink.
Indian Yellow.
Naples Yellow.
Lemon yellow.
Vandyke brown.
Venetian red.
Crimson lake.
Vermilion.
Rose madder.
Carmine.
Prussian blue and burnt sienna.
Prussian blue and Indian red.
Prussian blue and Vandyke brown.
Prussian blue and gamboge.
Indigo and Vandyke brown.
Indigo and burnt sienna.
Indigo and gamboge.
Indigo and Indian red.
Rose madder and raw sienna.
Antwerp blue and raw sienna.
Vermilion and chrome yellow.

Of the single colours we found that the gamboge, indigo, and Naples yellow had slightly faded. Brown pink had faded perceptibly to 6. Carmine had bleached to 3; Vandyke brown had faded to 1, and was fainter to 4, and crimson lake had faded to 5, and all the darker shades had become paler. With mixtures, Prussian blue and burnt sienna had changed, the blue had faded; with Prussian blue and Vandyke brown, and with indigo and Vandyke brown in both cases, the Vandyke brown had faded; with Prussian blue and gamboge, the gamboge had slightly gone in 1; with indigo and burnt sienna the indigo had gone in 1, and all the shades had become browner, indigo and gamboge had become paler throughout, both colours apparently fading; with indigo and Indian red, the indigo had gone completely in 1, and in part in all the tints. The other colours, both single and mixed, had not changed.

Conclusions.

XVII. In a subsequent report we hope to be able to make further deductions as to the causes which operate in producing the fading of pigments, but we can summarise the conclusions which are clearly to be drawn from the results of the experiments which we describe in this first report.

Mineral colours are far more stable than vegetable colours, and amongst those colours which have remained unaltered, or have only very slightly changed after an exposure to light of extreme severity, a good gamut is available to the water colour artist.

The presence of moisture and oyxgen are in most cases essential for a change to be effected, even in the vegetable colours. The exclusion of moisture and of oxygen, particularly when the latter is in its active condition, as experiments to be described in our next report show, would give a much longer life, even to these, than they enjoy when freely exposed to the atmosphere of a room. It may be said that every pigment is permanent when exposed to light "in vacuo," and this indicates the direction in which experiments should be made for the preservation of water colour drawings.

The effect of light on a mixture of colours which have no direct chemical action on one another is that the unstable colour disappears and leaves the stable colour unaltered appreciably.

Our experiments also show that the rays which produce by far the greatest change in a pigment are the blue and violet components of white light, and that these, for equal illumination, predominate in light from the sky, whilst they are less in sunlight and in diffused cloud light, and are present in comparatively small proportion in the artificial lights usually employed in lighting a room or gallery.

The experiments have also shown that about a century of exposure would have to given to water colour drawings in galleries lighted as are those at South Kensington before any very marked deterioration would be visible in them, if painted with any but the more fugitive colours; and that when the illumination is of the same quality as that of gaslight, or of the electric glow light rendered normally incandescent, and of the same intensity as that employed in those galleries, an exposure to be reckoned by thousands of years would have to be given to produce the same results. We have here not taken into account the action, if any, which might arise from the products of combustion where gaslight is the illuminant, and which our experiments so far have shown to have but a trifling effect, nor of any modification of hue which might be due to change in the whiteness of the paper on which the paintings were made, but simply to the change in the colours themselves. When it is determined what is the minimum illumination in which a water colour drawing can be well seen, the length of time during which the drawing will retain almost its pristine freshness can be easily calculated.

Since it is the blue light which causes the fading, it might be thought that the glazing of skylights with a glass of a slightly yellow tint should be adopted. It must be recollected, however, that in ordinary diffused sunlight this would entail an alteration in the brilliancy of the blues of a picture, and a change in their tone. It is well known to artists that a picture painted or illuminated by blue skylight looks colder than one illuminated by diffused sunlight, whether the diffusion be caused by white blinds to the gallery or by cloud. The cause of this will be apparent on looking at Fig. VI.; the red and yellow light are very deficient, whilst the blue light predominates. When the illumination is from the blue sky a yellow glaze or blind might be useful in imparting the warmer tone of diffused sunlight, and at the same time it would reduce in intensity the destructive component of the light.

We have to thank the Committee of Artists, appointed by the Science and Art Department for suggestions which they individually and collectively have made to us during our investigations, and for the criticisms which they have made on various points in our report. To us, who could only follow the subject from a purely scientific point of view, the ripe experience of those who are masters of its technique has been of the greatest value.

W. J. RUSSELL.
W. DE W. ABNEY.

PART III.

APPENDIX I.

Measurement of the intensity of light reflected from pigments.

We have already referred to the measures made of the colours with which we experimented, and we now give the results of the measurements made. For convenience of reference the curves of several pigments have been put in one diagram, and as far as possible those of the same colour appear together. These diagrams we believe will be found of great utility, since they show the exact optical properties of the pigments we used, and will be a guide in future investigations for ascertaining whether the same material is being dealt with. They also indicate the amount of fading which has taken place in those pigments which have not absolutely bleached, or in which no appreciable change has taken place.

For instance, a yellow pigment to the eye might be of approximately the same hue and luminosity as gamboge, but it is perfectly possible that the spectrum value of the two might be totally different. We have the same thing occurring in the mixture of spectrum colours. Thus, by mixing pure spectrum red with pure spectrum green, a yellow may be formed which to the eye may appear identical with the yellow found in the spectrum itself. Such a pigment might behave in the light quite differently to gamboge, either by being more permanent or more fugitive. Again, too, even the preparation of the same colour may vary. Thus cadmium yellow may be of a variety of tones, and of this variety some might behave somewhat differently in the light to that variety with which we have experimented.

In a paper recently communicated to the Royal Society, General Festing and one of us have shown how from these curves the exact colour of the pigment, or the faded pigment can be reproduced from the spectrum, and thus will enable any one who possesses the necessary apparatus to follow the results which we have obtained.

We have adopted in these curves the nomenclature of colours of the spectrum suggested by Professor Rood, as given in his "Modern Chromatics." Beneath each part of the curve the colour measured has been shown, and this may be of use for those who are not familiar with the Fraunhofer lines of the solar spectrum, the principal of which are indicated by B, C, D, &c.

In diagrams 13 and 14 we have given the readings of a series of tints of two colours with a view of showing the "reflection-capacity" of varying depths of tint. In diagram 13, No. 5 curve refers to No. 8 tint (*see* Fig. X.), and No. 1 curve to No. 4 tint. There were only three tints on the paper from which Diagram XIV. was made.

☞ In the following tables * before the colour signifies that the colour was unchanged after exposure to light; † that the colour bleached after exposure to light; †† that the alteration action was so small that it was not considered necessary to measure it.

INDIGO (Plate 1).

UNFADED.				FADED.			
Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,300	25·0	5,200	19·0	4,300	40·2	5,500	47·4
4,500	26·0	5,500	16·0	4,500	45·0	5,700	46·5
4,600	25·0	5,700	14·5	4,600	46·7	6,000	45·5
4,700	24·0	6,000	14·0	4,800	48·2	6,200	45·8
4,800	22·7	6,200	13·6	4,900	48·5	6,500	48·0
5,000	20·7	6,900	13·5	5,100	48·2	6,700	50·0
				5,300	47·8	6,900	52·0

ANTWERP BLUE (Plate 1).

UNFADED.				FADED.			
Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,200	76·5	6,000	32·0	4,200	47·5	5,500	57·0
4,300	75·5	6,100	30·8	4,300	53·0	5,600	53·0
4,400	74·8	6,200	30·2	4,400	57·8	5,700	49·5
4,500	75·0	6,400	28·7	4,500	61·5	5,800	46·4
4,600	76·5	6,600	27·5	4,600	64·5	5,900	43·4
4,700	78·0	6,900	26·2	4,700	66·3	6,000	40·0
4,800	77·0			4,800	67·8	6,100	37·5
4,900	73·2			4,825	68·0	6,200	35·5
5,000	69·5			4,900	66·0	6,300	34·0
5,200	62·0			5,000	63·8	6,400	33·0
5,400	53·5			5,100	63·0	6,500	32·3
5,600	45·5			5,200	64·0	6,600	32·0
5,800	38·0			5,300	63·2	6,900	32·0
5,900	34·6			5,400	61·0		

* COBALT BLUE (Plate 1).

Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,350	44·0	5,000	41·5	5,600	6·5	6,400	23·5
4,500	51·7	5,100	29·0	5,750	6·0	6,500	28·5
4,600	53·3	5,200	20·0	6,000	7·5	6,600	34·5
4,700	54·0	5,300	15·0	6,100	10·5	6,700	40·0
4,800	53·6	5,400	11·5	6,200	14·0		
4,900	50·5	5,500	8·5	6,300	18·5		

* FRENCH ULTRAMARINE (Plate 1).

Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,350	38·0	4,900	27·0	5,500	8·0	6,500	7·5
4,600	38·0	5,000	21·5	5,750	7·0	6,620	8·5
4,750	35·0	5,200	12·5	6,300	6·8	7,000	6·5

PRUSSIAN BLUE (Plate 2).

UNFADED.				FADED.			
Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,200	60·5	5,800	34·5	4,200	64·0	5,500	45·5
4,500	67·0	6,000	30·0	4,500	71·0	5,800	37·0
4,600	68·0	6,300	25·5	4,600	74·5	6,000	33·0
4,800	64·0	6,500	23·5	4,650	74·75	6,300	29·0
5,000	59·0	6,800	22·0	4,800	71·0	6,500	27·5
5,200	49·5	7,000	21·0	5,000	65·5	6,800	26·0
5,500	41·75			5,250	54·5	7,000	25·0

† PERMANENT BLUE (Plate 2).

Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,300	57·0	4,900	44·0	5,700	16·6	6,300	20·8
4,400	60·0	5,000	38·5	5,800	16·0	6,400	22·2
4,500	61·8	5,200	30·8	5,900	16·0	6,500	24·0
4,600	60·8	5,400	23·5	6,000	17·0	6,600	25·5
4,700	58·0	5,500	20·5	6,100	18·0		
4,800	51·0	5,600	18·0	6,200	19·3		

† FRENCH BLUE (Plate 2).

Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,250	40·0	4,750	58·5	5,750	24·3	6,500	34·5
4,400	47·0	4,900	48·0	5,850	24·0	6,600	36·5
4,500	54·0	5,000	43·7	6,000	25·2	6,700	37·5
4,600	61·0	5,100	40·2	6,200	28·2		
4,625	61·25	5,200	36·5	6,300	30·2		
4,700	60·5	5,400	31·0	6,400	32·7		

* CYANIN BLUE (Plate 2).

Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,300	45·5	4,900	50·5	5,500	26·8	6,100	10·5
4,400	49·2	5,000	46·5	5,600	23·0	6,200	9·5
4,500	52·6	5,100	42·8	5,700	19·5	6,300	9·0
4,600	55·5	5,200	38·5	5,800	16·5	6,500	8·2
4,700	57·0	5,300	34·5	5,900	14·0	6,800	7·0
4,800	54·8	5,400	30·5	6,000	12·0		

†† Emerald Green (Plate 3).

Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,200	25·0	5,000	72·5	5,700	39·7	6,400	9·0
4,300	25·75	5,125	75·0	5,800	32·0	6,500	8·0
4,500	29·0	5,200	73·5	5,900	26·0	6,600	7·6
4,600	34·5	5,300	69·5	6,000	20·5	6,750	7·0
4,700	49·0	5,400	63·0	6,100	16·5	7,000	6·5
4,800	60·0	5,500	55·5	6,200	13·4		
4,900	68·0	5,600	47·5	6,300	10·0		

* Green Oxide of Chromium (Plate 3).

Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,250	16·0	5,100	35·5	5,600	35·0	6,300	26·0
4,400	17·6	5,200	41·5	5,700	22·0	6,400	28·0
4,600	20·2	5,300	44·6	5,750	20·5	6,500	29·3
4,800	22·6	5,310	45·0	5,850	19·8	6,600	30·8
4,900	26·0	5,400	43·5	6,000	20·5	6,700	31·4
5,000	30·5	5,500	40·5	6,200	24·0	6,850	33·0

* Terra Verte (Plate 3).

Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,300	19·6	4,800	24·0	5,400	20·5	6,000	14·0
4,400	20·0	5,000	25·0	5,500	18·7	6,200	13·4
4,500	21·0	5,100	24·7	5,600	17·0	6,300	13·0
4,600	22·4	5,200	23·8	5,700	15·8	6,500	13·0
4,700	23·4	5,300	22·2	5,800	14·8		

PRUSSIAN BLUE, RAW SIENNA, AND BURNT SIENNA (Plate 4).

UNFADED.				FADED.			
Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,250	13·0	5,900	21·0	4,250	15·0	5,450	29·5
4,400	14·5	6,000	20·5	4,400	17·0	5,600	32·0
4,500	15·6	6,200	18·5	4,500	19·5	5,700	33·0
4,600	16·6	6,400	16·8	4,600	22·0	5,800	32·7
4,700	17·0	6,500	16·0	4,700	23·3	5,900	32·0
4,900	18·2	6,700	14·5	4,850	24·5	6,000	31·0
5,000	18·8	6,900	13·6	4,900	24·1	6,200	30·2
5,100	19·8			4,950	24·0	6,300	30·0
5,200	21·0			5,000	24·3	6,400	28·6
5,300	22·0			5,100	25·3	6,500	27·2
5,450	22·7			5,200	27·0	6,700	24·5
5,600	22·3			5,300	29·0	6,800	23·5
5,800	21·5			5,400	29·0		

INDIGO AND GAMBOGE (Plate 4).

Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,300	12·2	4,800	30·8	5,400	34·0	6,000	24·2
4,400	15·5	4,900	32·7	5,500	32·8	6,200	23·0
4,500	19·0	5,000	34·4	5,600	30·5	6,500	22·0
4,550	19·6	5,100	36·0	5,700	28·5	6,700	21·8
4,600	21·0	5,200	35·7	5,800	26·7	6,800	21·8
4,700	26·6	5,300	35·2	5,900	25·3		

† Antwerp Blue and Raw Sienna (Plate 4).

Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,300	9·5	4,900	16·0	5,500	17·4	6,100	10·3
4,500	12·3	5,000	17·0	5,600	15·8	6,200	9·7
4,600	12·3	5,100	18·0	5,700	14·7	6,500	8·3
4,650	12·7	5,200	18·3	5,800	13·3	6,700	7·8
4,700	13·3	5,250	18·5	5,900	12·2	6,900	7·3
4,800	14·8	5,400	18·0	6,000	11·0		

Prussian Blue and Gamboge (Plate 4).

Unfaded.				Faded.			
Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,300	22·5	5,400	46·5	4,300	37·5	5,500	37·8
4,400	25·0	5,500	43·5	4,400	39·0	5,600	35·3
4,500	31·0	5,600	40·2	4,500	47·0	5,700	32·7
4,600	38·5	5,700	36·5	4,600	53·6	5,800	30·4
4,650	40·5	5,800	32·5	4,700	51·4	5,900	28·0
4,700	43·4	5,900	29·5	4,800	50·2	6,000	26·3
4,800	48·8	6,000	27·5	4,900	50·0	6,200	25·0
4,900	51·7	6,100	26·2	5,000	49·5	6,500	24·6
5,000	53·0	6,200	25·3	5,100	47·0	6,850	24·4
5,100	52·7	6,400	24·8	5,200	45·0		
5,200	51·3	6,850	23·0	5,300	42·5		
5,300	49·0			5,400	40·2		

†† VERMILION (Plate 5).

Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,350	6·75	5,500	11·5	5,900	59·0	6,600	90·5
4,800	6·75	5,600	15·0	6,000	78·0	6,750	84·0
5,000	7·5	5,750	31·5	6,200	97·0	7,000	72·5
5,300	9·5	5,800	40·0	6,500	94·5		

MERCURIC IODIDE (Plate 5).

Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,300	3·0	5,000	3·7	5,800	29·5	6,400	74·5
4,500	2·0	5,200	5·5	5,900	54·5	6,500	75·4
4,600	4·0	5,400	6·8	6,000	66·5	6,600	75·8
4,750	5·8	5,500	8·0	6,100	70·0	6,750	76·3
4,900	4·2	5,700	18·0	6,200	71·7	7,000	76·3
4,950	3·5	5,750	22·0	6,300	73·5		

† CARMINE (Plate 5).

Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,300	37·0	5,200	31·5	5,700	41·0	6,400	75·0
4,500	38·5	5,300	33·0	5,800	50·0	6,500	76·0
4,550	39·0	5,380	34·5	5,900	59·0	6,600	75·0
4,700	36·5	5,450	33·5	6,000	67·0	6,800	72·0
4,800	34·5	5,500	33·0	6,100	70·5		
5,000	32·0	5,550	33·25	6,200	72·1		
5,100	31·0	5,600	34·0	6,300	74·0		

* INDIAN RED (Plate 5).

UNFADED.				FADED.			
Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,200	25·7	5,750	42·5	4,200	27·5	5,800	49·5
4,300	27·0	5,800	48·5	4,300	29·0	5,900	54·0
4,500	29·5	5,900	52·0	4,500	28·6	6,000	61·5
4,750	30·5	6,000	58·5	4,600	28·5	6,100	65·5
4,900	30·0	6,100	63·2	4,750	29·0	6,200	68·5
5,000	29·3	6,200	66·5	5,000	30·0	6,250	70·3
5,150	29·0	6,250	67·5	5,250	31·5	6,400	74·5
5,300	30·0	6,400	70·6	5,400	34·0	6,500	77·0
5,400	31·5	6,500	72·5	5,500	36·5	6,700	81·5
5,500	33·5	6,990	76·0	5,600	40·0	6,990	87·0
5,600	36·3			5,750	46·5		

† CRIMSON LAKE (Plate 6).

Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,250	18·8	5,100	10·5	5,700	23·6	6,300	82·5
4,500	19·5	5,200	11·5	5,800	31·5	6,400	84·0
4,575	19·6	5,300	14·0	5,900	42·5	6,500	83·5
4,600	19·0	5,400	15·0	6,000	54·5	6,600	83·0
4,700	16·5	5,475	14·0	6,100	65·5	6,700	81·5
4,800	14·2	5,500	14·5	6,200	76·3	6,900	78·8
5,000	11·5	5,600	18·0	6,250	80·2	7,000	77·8

ROSE MADDER (Plate 6).

UNFADED.				FADED.			
Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,200	30·0	5,600	22·5	4,200	45·5	5,400	34·0
4,300	31·0	5,700	32·5	4,300	45·5	5,500	38·0
4,400	32·0	5,800	49·0	4,400	45·0	5,600	42·5
4,500	31·0	5,900	58·0	4,500	45·1	5,700	48·0
4,600	27·0	6,000	65·0	4,600	46·0	5,800	54·0
4,700	22·6	6,100	70·0	4,700	41·5	5,900	58·5
4,800	20·5	6,200	73·0	4,800	37·3	6,000	63·0
4,900	19·8	6,300	77·0	4,800	34·2	6,100	67·5
5,000	18·5	6,400	78·6	4,950	34·0	6,200	71·5
5,100	18·0	6,500	79·6	5,000	32·7	6,300	74·2
5,250	17·2	6,700	80·0	5,100	32·0	6,400	75·0
5,400	18·2			5,200	33·0	6,500	73·8
5,500	19·0			5,300	33·1	6,700	69·4

† SCARLET LAKE (Plate 6).

Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,250	36·5	5,000	25·5	5,700	41·0	6,300	81·5
4,400	34·0	5,150	25·0	5,800	50·5	6,400	80·6
4,500	32·5	5,200	25·2	5,900	62·0	6,500	80·0
4,600	31·7	5,300	26·0	6,000	76·0	6,800	77·0
4,700	30·5	5,500	29·5	6,100	82·0		
4,800	28·2	5,600	34·0	6,200	82·0		

* VENETIAN RED (Plate 6).

Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,200	22·5	5,000	30·5	5,700	58·0	6,200	87·5
4,300	25·0	5,200	31·5	5,750	61·0	6,300	90·5
4,400	27·7	5,300	32·5	5,800	65·0	6,400	92·2
4,500	29·5	5,400	34·5	5,900	72·0	6,500	93·3
4,550	30·0	5,500	39·5	6,000	78·5	6,620	94·0
4,750	30·0	5,600	47·0	6,100	83·5		

* BURNT SIENNA (Plate 7).

Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,350	9·0	5,100	18·8	5,800	42·6	6,400	61·5
4,500	13·0	5,200	20·8	5,900	48·3	6,500	61·0
4,600	15·5	5,300	23·4	6,000	54·0	6,575	60·6
4,700	16·8	5,400	26·2	6,100	57·0	6,600	60·8
4,800	17·0	5,500	30·0	6,200	59·5	6,700	61·6
4,900	17·0	5,600	33·8	6,300	61·0	6,800	63·0
5,000	17·5	5,700	38·0	6,375	61·6		

BROWN MADDER (Plate 7).

UNFADED.				FADED.			
Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,350	33·6	5,600	46·0	4,350	64·5	5,600	74·9
4,500	34·3	5,700	47·5	4,500	66·0	5,700	74·5
4,700	38·0	5,800	49·4	4,600	69·0	5,800	74·0
4,800	38·8	5,900	51·8	4,700	75·0	5,900	76·0
4,900	38·0	6,000	54·5	4,775	79·5	6,000	81·2
5,000	37·5	6,200	59·0	4,800	79·0	6,100	87·0
5,150	37·3	6,300	60·5	4,900	75·8	6,200	89·6
5,300	38·5	6,500	63·0	5,000	74·0	6,300	89·0
5,400	40·4	6,700	64·4	5,200	74·5	6,500	90·5
5,500	43·0	6,800	65·0	5,400	75·0	6,600	93·5

† Burnt Umber (Plate 7).

Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,300	34·5	5,000	45·6	5,600	62·0	6,200	75·8
4,450	36·0	5,100	48·0	5,700	66·5	6,300	76·8
4,650	36·0	5,200	50·2	5,800	70·5	6,500	79·0
4,700	37·3	5,300	52·0	5,900	72·0	6,600	80·6
4,800	40·0	5,400	54·0	6,000	73·4		
4,900	42·8	5,500	57·5	6,100	74·7		

† Purple Madder (Plate 8).

Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,300	15·2	5,000	16·0	5,700	24·0	6,400	49·5
4,400	16·2	5,100	16·3	5,800	26·5	6,500	51·5
4,450	17·2	5,200	17·2	5,900	30·7	6,600	53·0
4,500	16·7	5,300	18·4	6,000	35·0	6,700	54·0
4,600	15·5	5,400	18·8	6,100	39·5	6,900	54·0
4,750	15·6	5,500	20·0	6,200	43·5		
4,900	15·8	5,600	22·8	6,300	46·6		

† Brown Pink (Plate 8).

Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,350	8·5	5,200	22·5	5,800	34·0	6,400	45·5
4,500	11·0	5,300	24·0	5,900	36·2	6,500	46·5
4,700	14·5	5,400	26·3	6,000	38·5	6,600	47·0
4,800	16·0	5,500	28·2	6,100	40·8	6,700	47·5
5,000	19·4	5,600	30·0	6,200	42·5	6,800	48·0
5,100	21·0	5,700	32·0	6,300	44·0	6,850	48·0

† SEPIA (Plate 8).

Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,300	9·0	4,750	12·0	5,500	13·5	6,200	27·0
4,400	11·8	4,800	12·3	5,600	13·5	6,300	27·0
4,500	12·5	5,000	12·5	5,700	14·2	6,500	26·5
4,550	13·0	5,200	13·5	5,800	15·0	6,600	26·2
4,700	12·3	5,300	14·0	6,000	26·5		

† VIOLET CARMINE (Plate 8).

Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,300	14·0	5,250	10·7	6,000	15·5	6,600	44·7
4,500	14·5	5,350	10·5	6,100	23·0	6,700	46·5
4,750	13·6	5,500	10·5	6,250	34·0	6,800	47·0
5,000	12·0	5,750	11·0	6,300	36·5		
5,100	11·0	5,900	12·6	6,500	42·5		

CRIMSON LAKE AND ANTWERP BLUE (Plate 9).

UNFADED.				FADED.			
Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,200	44·5	6,000	43·0	4,200	62·5	5,700	53·0
4,400	49·0	6,200	44·0	4,300	63·8	5,800	49·0
4,575	53·0	6,400	43·5	4,400	63·5	5,900	45·5
4,700	50·5	6,600	42·5	4,500	64·0	6,000	43·0
4,800	46·8	6,800	40·7	4,600	68·0	6,200	39·0
4,900	44·3	6,900	39·6	4,750	72·3	6,300	37·2
5,000	43·0			4,900	71·5	6,400	36·0
5,200	42·0			5,000	70·0	6,500	35·2
5,400	41·5			5,200	67·5	6,700	33·5
5,600	41·6			5,400	63·0	6,900	31·0
5,800	42·3			5,500	60·5		

ROSE MADDER AND RAW SIENNA (Plate 9).

Unfaded.				Faded.			
Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,300	29·0	5,500	35·5	4,300	29·5	5,400	35·5
4,400	29·5	5,550	36·0	4,400	30·8	5,500	38·0
4,500	31·0	5,600	37·0	4,500	32·5	5,600	45·0
4,600	33·0	5,700	50·0	4,575	33·5	5,700	54·0
4,700	32·2	5,800	63·0	4,700	31·6	5,800	63·0
4,800	31·5	5,900	81·0	4,800	30·5	5,900	68·0
4,900	29·2	6,000	76·0	4,900	30·0	6,000	71·5
5,000	26·5	6,100	79·5	5,000	28·0	6,100	74·2
5,100	25·0	6,200	82·0	5,075	26·0	6,200	76·0
5,200	29·5	6,300	83·6	5,100	26·4	6,400	78·4
5,300	33·5	6,500	85·0	5,200	31·6	6,600	79·5
5,400	34·5	6,800	85·0	5,300	35·0	6,800	80·0

INDIAN RED AND INDIGO (Plate 10).

Unfaded.				Faded.			
Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,200	28·5	5,900	34·5	4,250	37·5	5,600	54·6
4,500	33·5	6,000	34·6	4,400	41·5	5,700	56·0
4,600	35·0	6,200	34·3	4,500	43·6	5,900	58·3
4,700	36·0	6,300	33·6	4,700	45·5	6,000	59·0
4,750	35·5	6,500	33·0	4,900	47·0	6,200	60·7
4,900	34·2	6,800	33·0	5,000	47·5	6,400	62·3
5,000	33·4			5,200	49·2	6,500	63·0
5,200	33·0			5,300	50·0	6,700	64·6
5,500	33·5			5,400	51·2	6,900	66·4
5,700	33·9			5,500	53·0		

VENETIAN RED AND INDIGO (Plate 10).

UNFADED.				FADED.			
Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,300	23·3	5,700	28·0	4,250	27·0	5,700	46·0
4,500	25·5	5,800	28·0	4,300	28·0	5,800	49·5
4,700	27·8	6,000	28·3	4,500	31·5	5,900	52·0
4,800	27·5	6,200	29·3	4,700	34·2	6,000	53·0
4,900	27·0	6,300	30·0	4,800	35·0	6,200	54·5
5,000	26·8	6,400	31·0	5,000	35·6	6,300	55·0
5,100	26·5	6,500	31·6	5,200	36·5	6,400	55·6
5,200	26·8	6,600	31·2	5,300	37·2	6,500	56·0
5,400	27·0	6,700	30·0	5,400	38·2	6,700	56·7
5,500	27·5	6,900	27·2	5,500	40·0	6,800	57·2
5,600	27·8			5,600	44·0	6,900	57·8

† INDIAN YELLOW AND ROSE MADDER (Plate 10).

Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,300	11·0	5,200	11·5	5,800	41·0	6,500	73·5
4,500	12·6	5,300	12·6	5,900	49·5	6,600	74·0
4,700	13·8	5,400	14·8	6,000	57·0	6,800	73·0
4,800	12·8	5,500	17·8	6,200	68·0		
4,900	11·6	5,600	23·2	6,300	71·4		
5,050	10·8	5,700	31·8	6,400	72·6		

† GAMBOGE (Plate 11).

Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,275	15·0	4,650	18·5	5,300	60·5	6,200	81·7
4,300	14·5	4,750	21·5	5,400	67·5	6,350	82·4
4,375	13·7	4,900	28·5	5,500	73·0	6,500	82·6
4,500	16·0	5,000	36·5	5,700	75·5	6,700	82·8
4,550	17·5	5,200	53·5	5,900	78·5	6,800	83·0
4,600	18·0	5,250	57·5	6,000	80·0		

† INDIAN YELLOW (Plate 11).

Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,250	18·5	4,900	54·5	5,600	77·7	6,300	89·0
4,300	21·5	5,000	58·5	5,700	79·3	6,400	91·5
4,400	27·0	5,100	62·5	5,800	80·3	6,500	93·5
4,500	32·5	5,200	66·0	5,900	81·0	6,600	95·0
4,600	38·5	5,300	69·6	6,000	82·6	6,700	96·3
4,700	43·8	5,400	72·6	6,100	84·3	6,900	98·0
4,800	49·0	5,500	75·4	6,200	86·5		

† CADMIUM YELLOW (Plate 11).

Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,200	21·5	5,000	42·0	5,600	88·5	6,200	92·0
4,400	22·5	5,100	49·5	5,700	91·5	6,300	89·5
4,500	23·5	5,200	57·5	5,800	93·5	6,400	86·7
4,700	28·0	5,300	65·0	5,900	94·6	6,500	84·0
4,800	32·0	5,400	73·0	6,000	95·0	6,750	77·0
4,900	37·0	5,500	80·5	6,100	94·0		

* YELLOW OCHRE (Plate 11).

Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,375	15·5	4,900	25·5	5,500	67·5	6,200	78·0
4,500	21·5	5,000	29·3	5,600	75·5	6,300	77·5
4,550	21·6	5,100	34·0	5,750	79·5	6,400	77·5
4,600	21·0	5,200	40·5	5,800	80·0	6,550	77·5
4,750	21·7	5,300	49·0	5,900	79·5		
4,800	23·0	5,400	59·0	6,000	79·0		

* CHROME YELLOW (Plate 12).

Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light,	Wave Length.	Intensity of Reflected Light.
4,350	30·0	5,000	68·5	5,600	94·5	6,400	91·5
4,500	30·7	5,100	76·5	5,750	89·5	6,500	91·0
4,600	32·5	5,200	80·5	5,870	87·0	6,700	89·5
4,700	37·5	5,300	86·5	6,000	89·5	7,000	87·7
4,750	44·5	5,400	91·5	6,100	91·0		
4,800	51·5	5,500	95·0	6,200	92·0		
4,900	61·5	5,550	96·0	6,300	92·0		

† NAPLES YELLOW (Plate 12).

Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,300	44·5	4,800	48·3	5,300	83·8	6,000	100·0
4,400	43·3	4,900	53·7	5,400	90·0	6,200	99·8
4,500	42·7	5,000	60·0	5,500	94·0	6,500	97·3
4,600	43·0	5,100	67·5	5,600	96·5	6,800	92·0
4,700	45·0	5,200	76·0	5,700	98·2	6,850	90·5

† AUREOLIN (Plate 12).

Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,250	15·0	4,800	25·0	5,400	83·0	6,150	93·0
4,350	13·0	4,900	33·0	5,500	89·0	6,300	93·5
4,400	14·0	5,000	42·0	5,600	92·7	6,400	94·0
4,500	15·7	5,100	53·0	5,700	93·5	6,500	94·6
4,600	16·2	5,200	65·0	5,800	94·0	6,620	96·0
4,700	19·0	5,300	75·5	6,000	93·5		

* FIVE SHADES OF RAW SIENNA (Plate 13).

No. 1.

Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,300	10·0	5,000	25·5	5,600	58·0	6,200	72·4
4,400	14·5	5,100	28·5	5,700	64·0	6,500	73·2
4,500	16·5	5,200	32·0	5,800	67·5	7,000	73·5
4,700	19·0	5,300	37·0	5,900	69·5		
4,900	23·0	5,500	50·0	6,000	71·0		

No. 2.

Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,300	19·5	4,900	34·0	5,500	61·5	6,200	80·5
4,400	24·0	5,000	36·0	5,600	68·5	6,500	81·0
4,500	27·3	5,100	39·0	5,700	73·2	7,000	81·3
4,600	29·2	5,200	42·5	5,800	77·0		
4,700	30·5	5,300	47·5	5,900	78·5		
4,800	32·0	5,400	53·0	6,000	79·5		

FIVE SHADES OF RAW SIENNA—*cont.*

No. 3.

Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,300	28·0	4,900	43·5	5,500	71·0	6,000	90·5
4,400	32·5	5,000	47·5	5,600	77·5	6,200	91·5
4,500	34·6	5,100	50·8	5,700	82·5	6,500	91·5
4,700	37·4	5,200	54·6	5,800	86·2	7,000	91·5
4,800	40·7	5,400	65·0	5,900	88·8		

No. 4.

Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,300	35·0	5,000	57·0	5,600	87·5	6,000	94·5
4,500	40·5	5,200	65·5	5,700	90·6	6,300	95·5
4,700	45·5	5,400	77·0	5,800	92·6	6,500	95·5
4,800	49·0	5,500	83·0	5,900	93·6	7,000	95·5

No 5.

Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,300	39·5	5,000	61·5	5,600	93·2	6,200	98·0
4,500	44·5	5,200	72·3	5,700	95·0	7,000	98·0
4,700	50·0	5,400	85·0	5,900	97·3		
4,800	53·2	5,500	90·0	6,000	98·0		

THREE SHADES OF PRUSSIAN BLUE AND CHINESE WHITE (Plate 14).

No. 1.

Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,300	49·0	4,700	51·0	5,700	18·8	6,700	7·3
4,400	51·0	4,900	43·4	5,800	16·5	7,000	7·0
4,500	53·5	5,200	35·0	6,000	12·8		
4,550	54·0	5,400	28·3	6,400	8·4		
4,600	53·5	5,600	22·0	6,500	8·0		

No. 2.

Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,300	51·5	4,800	62·0	5,900	25·5	6,700	14·2
4,400	54·0	5,000	56·6	6,000	23·2	7,000	12·8
4,500	58·0	5,300	47·0	6,400	17·0		
4,600	62·0	5,500	40·0	6,500	16·0		
4,700	63·3	5,800	28·0	6,600	15·0		

No 3.

Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.	Wave Length.	Intensity of Reflected Light.
4,300	61·0	5,000	71·6	5,900	41·6	6,600	31·0
4,400	65·0	5,200	66·8	6,000	39·0	6,800	29·7
4,600	71·5	5,400	61·0	6,100	36·5	7,000	29·0
4,700	73·5	5,600	53·5	6,200	35·0		
4,800	74·0	5,700	49·0	6,400	32·4		
4,900	73·5	5,800	45·3	6,500	31·6		

The original curves were made on the scale given by the prisms used, but for convenience they have been converted into the normal wave-length scale. The tables which precede each diagram are the tables of the intensities of the different colours of the spectrum reflected from the various pigments, the intensity of those reflected from a white surface being taken as 100. Thus if we turn to Plate I. and look at the curve for carmine, we find that in the red at wave-length 6,000 it reflects 67 of light; that is, it reflects 67 °/₀ of the light which a white surface reflects. Again in Prussian blue at wave-length 4,600 it reflects 68 of light, which is equivalent to saying that it reflects 68 °/₀ of that reflected from a white surface.

It may here be well to point out that the true colour of the pigment can be ascertained by drawing a line parallel to the base of the curve and touching the lowest point in it. This abstracts from the curve of intensities all the white light reflected from the surface of the particles, leaving only the intensities of the rays which go to form the true colour.

Curves of green, red, and blue glass.

At page 18 has been given the curves of the light transmitted through red, green, and blue glass at different parts of the spectrum.

The following table gives the heights of the curves at any point of the spectrum.

The light before its passage being taken as 100.

Red Glass.		Green Glass.		Blue Glass.	
Scale Number.	Intensity.	Scale Number.	Intensity.	Scale Number.	Intensity.
0·5	35	2	0·3	0·8	4·2
1	35	3	1·0	1·8	3·4
2	33·5	4	3·0	2·3	2·1
3	30	5	6·3	2·8	0·5
4	19	6	10·7	3·8	1·1
4·5	14	7·5	15·0	5·0	0·0
5	10	7	15·5	6·0	2·0
6	6	8	16·0	6·5	2·5
7	3	9	14·0	7·0	1·0
7·5	0	10	10·5	8·0	1·0
		11	8·0	9·0	1·0
		12	6·0	10·0	2·0
		13	5·0	11·0	4·0
		14	4·0	12·0	12·0
		15	2·7	13·0	23·0
		16	1·7	14·0	34·0
		18	0·0	15·0	45·0
				16·0	56·0
				17·0	62·0
				18·0	65·0

APPENDIX II.

In reference to the calculations which have been given regarding the value of the intensities of the blue rays in sunlight and skylight, the following results will be of interest.

Calculations of the intensity of sunlight, &c.

Experiment has shown that the white hot crater in the positive carbon pole of the electric light always emits the same quality of light with great constancy, and therefore is a very convenient standard of light to use, since the blue rays are present in great abundance in it.

The light from this source was by proper means reduced to the light of one candle, and at one foot distance from the photometer, the blue rays were found to have a value of 3·627 units of an empyric standard.

Sunlight on a surface held normally to the direction of the beam on the 21st May near midday, the sky being very clear, had a value of 19,900 of these same units, which is equivalent to saying that it had a value of 5,480 candles at 1 foot off the surface as measured by the blue rays.

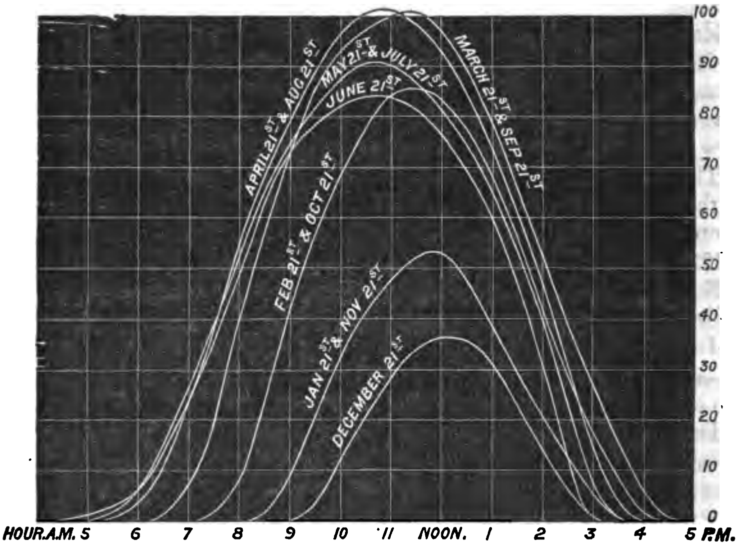
In text books it is said that sunlight has an illuminating power equal to about 5,600 candles at one foot distance from a surface, but it is not stated at what time of the day or year this value was obtained. As the proportion of blue rays in sunlight near midday in May is very nearly the same as in the standard light employed, it would appear that the text book value is almost identical with our estimate.

The scale of units of work was obtained by taking empyrically that one candle (of the quality electric light) performed 3·627 units of work in 30 minutes. This makes sunlight of the quality of that measured near midday on the 21st May perform 19,900 units in the same time. The candle power in the above table was derived from the units of work performed during the whole of daylight.

Value of sunlight falling on vertical surface.

The following figure gives a measure of the candle power of sunlight falling on a vertical surface in the same position as that in which the pigments were exposed on the 21st day of each month. The absorption by the atmosphere of these rays has been taken as ·6 for each atmosphere traversed, an estimate which careful observations, carried on for a long period, shows to be the mean absorption value, one atmosphere being taken as the height traversed by a beam of light were the sun vertical. To prevent confusion in the figure the scale of the intensity has been multiplied by three, the unit being 100; hence at any time of day the candle power of the blue light measured from the curves can be obtained by dividing the ordinate of the curve by three. Thus at 9 a.m. on the 21st of August the height of the curve is 7,860; this gives a candle power of sunlight at that day and hour of 2,620.

Fig. XII.



The following table gives the numerical results of the diagram. As before said these have been multiplied by three in the latter.

ILLUMINATING VALUE IN CANDLES OF SUNLIGHT FALLING ON A VERTICAL SURFACE FACING 20° E. of N.

—	4 a.m.	5 a.m.	6 a.m.	7 a.m.	8 a.m.	9 a.m.	10 a.m.	11 a.m.	Noon.	1 p.m.	2 p.m.	3 p.m.	4 p.m.
Jan. 21					0	260	1,090	1,530	1,720	1,270	720	130	0
Feb. 21				0	280	1,390	2,300	2,820	2,740	2,340	1,420	631	59
Mar. 21			0	213	1,350	2,350	3,100	3,320	3,240	2,630	1,740	910	150
Apr. 21		0	95	795	1,790	2,620	3,180	3,340	3,100	2,460	1,590	650	0
May 21		0	182	860	1,700	2,410	2,890	3,010	2,690	2,100	1,330	320	0
June 21		0	160	770	1,620	2,410	2,730	2,800	2,510	2,090	1,060	0	0
July 21		0	182	860	1,700	2,410	2,890	3,010	2,690	2,100	1,330	320	0
Aug. 21		0	95	795	1,790	2,620	3,180	3,340	3,100	2,460	1,590	650	0
Sept. 21			0	213	1,350	2,350	3,100	3,320	3,240	2,630	1,740	910	150
Oct. 21				0	280	1,390	2,300	2,820	2,740	2,340	1,420	631	59
Nov. 21					0	260	1,090	1,530	1,720	1,270	720	130	0
Dec. 21					0		372	930	1,260	1,100	550	23	0

The amount of loss of illumination due to the surface being vertical and not normal to the direction of the beam of light will be shown by taking as an example August 21st.

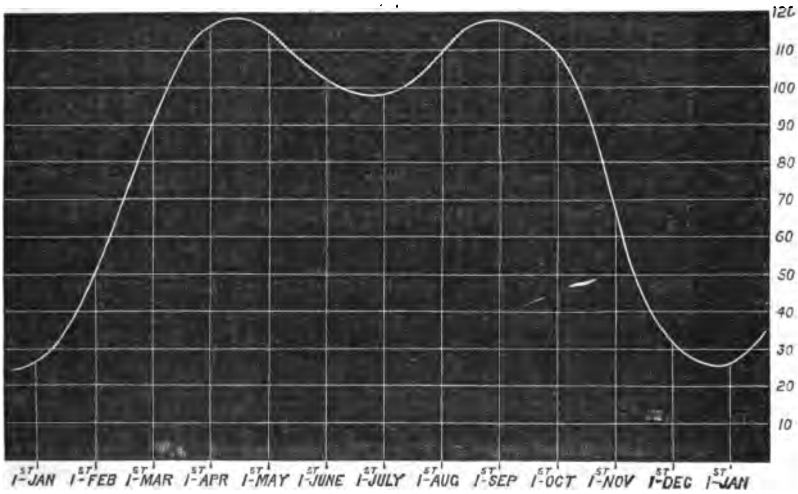
—	5 a.m.	6 a.m.	7 a.m.	8 a.m.	9 a.m.	10 a.m.	11 a.m.
Aug. 21	180	1,550	3,000	4,040	4,640	5,180	5,460

Noon.	1 p.m.	2 p.m.	3 p.m.	4 p.m.	5 p.m.	6 p.m.	7 p.m.
5,480	5,460	5,180	4,640	4,040	3,000	1,550	180

The above tables are close approximations to the true values. It should be stated that the sun's declination has also been taken as equal on the 21st of January and November, February and October, March and September, April and October, and May and November. This is not quite exact, but will make no practical difference in the results.

The total units of work which sunshine would perform during the whole day, supposing the sky cloudless, is found by taking the areas of these curves. Fig. XIII. shows the work in the units we have adopted, but multiplied by three

Fig. XIII.



for every portion of the year, the units being the height of the curves. It will be seen that from the beginning of March to the end of September the work performed is very much greater than in the remaining portions of the year.

APPENDIX III.

Value of the light in a gallery at South Kensington Museum.

The following table gives the mean light expressed in candle power at a distance of one foot from the object and measured by the blue rays falling on the wall of one of the South Kensington galleries. The values are deduced from measurements made during the whole day on various days in March, April, May, and June. The various galleries in the Museum differ very slightly in the quantity of light which falls on the walls.

VALUE OF LIGHT IN THE GALLERY.

Date.	Mean Candle Illumination.	Units of Work during the whole Day.	Date.	Mean Candle Illumination.	Units of Work during the whole Day.
March 23	3·57	364	May 1	21·4	2,640
24	6·25	605	2	18·0	2,218
25	9·53	965*	3	28·5	3,502
26	16·00	1,625	4	26·8	3,388
27	8·4	859	5	27·8	4,560
28	13·4	1,415	6	3·0	365*
29	13·0	1,396	15	20·0	2,628
30	4·0	420	16	22·5	2,925
31	10·3	1,121	17	36·2	4,740
April 1	4·4	480*	18	28·5	3,600
2	14·2	1,912	26	9·8	1,260
3	3·8	1,500	27	4·1	564*
4	4·8	523	28	10·8	1,400
5	8·4	921	29	16·0	2,180
6	8·6	938	30	26·3	3,600
7	10·6	1,167	31	19·2	2,626
8	3·7	430*	June 1	16·0	2,220
9	15·7	1,708	2	17·4	2,420
10	10·5	1,153	3	8·6	1,200*
11	15·8	1,724	4	13·1	1,813
19	12·8	1,498	5	2·2	3,160
20	28·8	3,350	6	9·8	1,230
21	31·2	3,660	7	24·0	3,460
22	1·2	136*	8	23·4	3,300
26	26·5	3,230	10	11·7	3,300
27	36·8	4,200	11		
28	14·1	1,789	12	28·0	4,200
29	4·0	487*			
30	10·0	1,334			

Those dates marked with (*) are Sundays, when the blinds in the galleries are closely drawn.

APPENDIX IV.

The Science and Art Department invited some of the most distinguished artists who used water colours to furnish a list of the colours which they employed: 46 responses were received to the invitation, and the following is a tabulated list of the colours used.

For convenience, a distinguishing number has been allotted to each of the artists from whom a list of colours has been received, and the colours used by each artist are indicated by means of this distinguishing number.

LIST OF COLOURS INDICATING THE NUMBER OF ARTISTS BY WHOM THEY ARE USED.

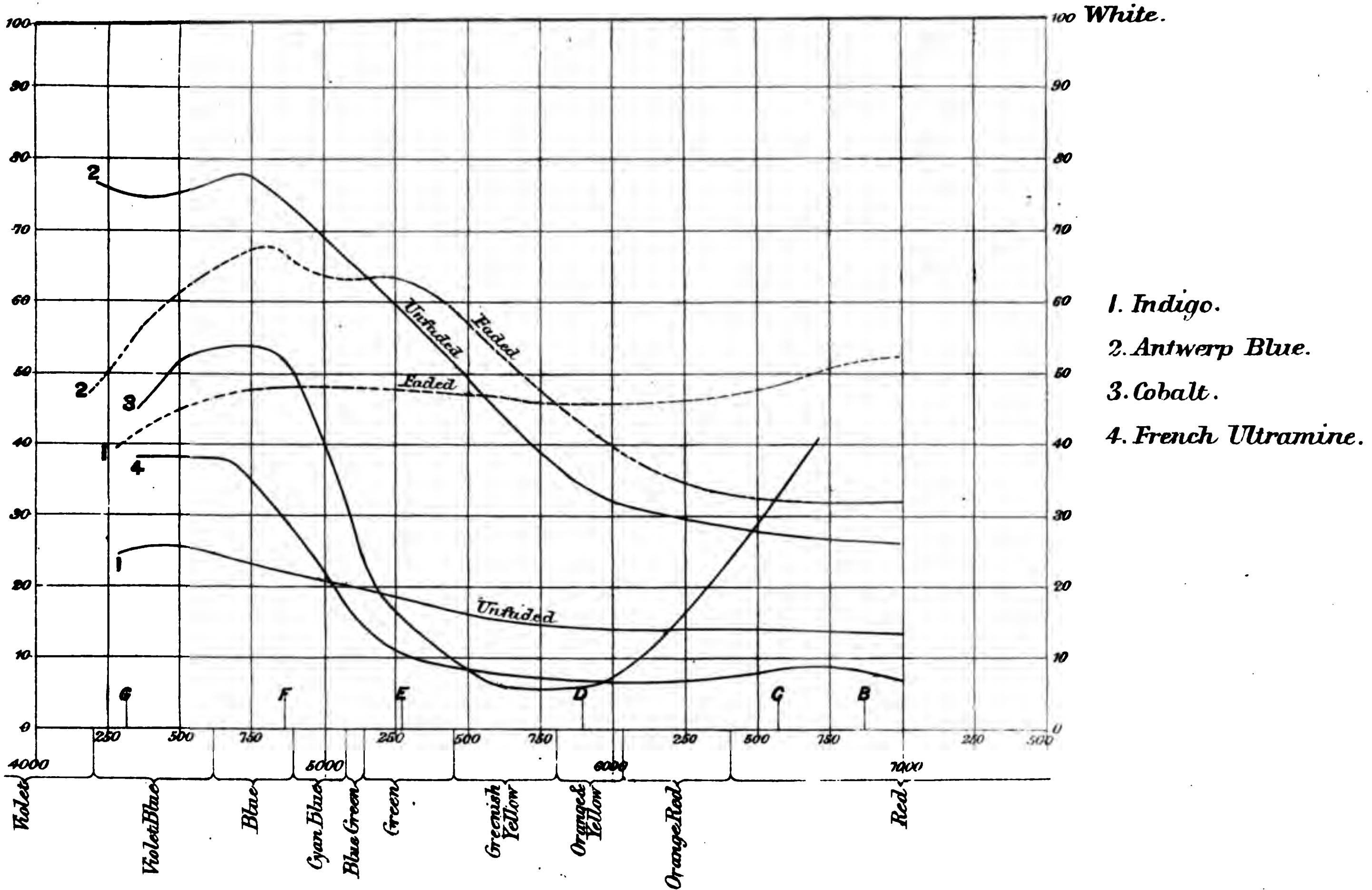
Number of Artists by whom used.	Colours.	Distinguishing Number of Artist.
	BLACK.	
1	Asphaltum - - -	27.
2	Black - - -	13, 26.
3	Blue Black - - -	5, 20, 27.
1	Charcoal - -	17.
1	Graphito . - - -	27.
11	Ivory Black - -	8, 12, 14, 27, 28, 30, 33, 38, 40, 42, 46,
14	Lamp Black - - -	1, 3, 4, 7, 10, 12, 18, 21, 23, 25, 31, 36, 39, 43.
1	Neutral Tint - -	42.
1	Persian Black - -	34.
1	Roman Sepia - -	39.
30	Sepia - - - -	1, 2, 3, 5, 6, 7, 10, 11, 12, 13, 15, 17, 23, 24, 25, 26, 27, 28, 30, 31, 34, 35, 37, 38, 39, 40, 42, 43, 44, 45.
1	Warm Sepia - -	32.
	BLUE.	
6	Antwerp Blue - -	2, 4, 12, 18, 30, 38.
9	Azure Blue (or Ceruleum)	10, 16, 22, 23, 28, 31, 39 (Newman's) 40, 41.
	Ceruleum (or Azure Blue)	[See above.]

Number of Artists by whom used.	Colours.	Distinguishing Number of Artist.
	BLUE—*continued.*	
45	Cobalt - - - -	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46.
8	Cyanine Blue - -	7, 11, 22, 23, 27, 29, 33, 39.
5	French Blue - - -	5, 9, 12, 16, 31.
18	French Ultramarine -	[See under Ultramarine.]
24	Indigo - - -	3, 4, 6, 10, 11, 12, 14, 16, 17, 19, 23, 24, 25, 30, 31, 34, 37, 39, 41, 42, 43, 44, 45, 46.
2	Leicht's Blue - -	24, 25.
16	Prussian Blue - -	4, 7, 8, 10, 12, 13, 14, 17, 21, 28, 32, 36, 39, 42, 43, 44.
2	Smalt - -	15, 21.
15	Ultramarine (Real) -	1, 7, 12, 14, 17, 18, 21, 27, 28, 35, 37, 39, 40, 42, 46.
	„ (French) -	3, 6, 7, 14, 15, 18, 20, 25, 28, 29, 30, 33, 34, 36, 38, 39, 40, 46.
18	Ultramarine Ash - -	2, 3, 4, 7, 12, 14, 15, 21, 22, 27, 30, 33, 34, 35, 40, 43, 45, 46.
1	„ „ (Blue) -	11.
1	„ „ (Grey) -	11.
	BROWN.	
2	Bistre - - -	34, 39.
33	Brown Madder - -	[See under Madders.]
3	„ Ochre - -	[See under Ochres.]
41	Burnt Sienna - -	[See under Siennas.]
18	„ Umber - -	[See under Umbers.]
2	Cologne Earth - -	7, 12.
38	Raw Sienna - -	[See under Siennas.]
26	„ Umber - - -	[See under Umbers.]
2	Turner Brown - -	11, 27.
33	Vandyke Brown - -	1, 2, 3, 4, 5, 7, 8, 9, 10, 12, 13, 15, 16, 17, 18, 20, 22, 23, 25, 26, 30, 31, 32, 35, 36, 38, 39, 40, 42, 43, 44, 45, 46.
	GREEN.	
5	Emerald Oxide of Chromium.	3, 4, 15, 21, 32.
13	Emerald Green - -	5, 6, 7, 10, 12, 22, 24, 30, 33, 36, 38, 39, 46.
7	Oxide of Chromium -	3, 6, 15, 20, 30, 33, 38.
6	„ „ (Transparent.)	7, 23, 27, 36, 40, 46.
4	„ „ (Opaque)	7, 27, 36, 40.
5	Olive Green - -	6, 12, 29, 31, 32.
11	Terre Verte - -	7, 11, 22, 23, 30, 34, 35, 36, 40, 44, 46.
3	Veronese Green - -	26, 31, 40.
4	Cobalt Green - -	23, 26, 33, 34.
1	Transparent Green - -	33.
5	Viridian - - -	10, 15, 20, 40, 41.
1	Miscellaneous kinds -	40.

Number of Artists by whom used.	Colours.	Distinguishing Number of Artist.
	GREY.	
3	Charcoal Grey - -	3, 14, 16.
3	Payne's Grey - - -	34, 45, 46.
1	Ultramarine Ash (Grey)	[See under Bluo.]
	RED.	
6	Brown Pink - -	12, 19, 37, 39, 42, 45.
4	Carmine - -	9, 16, 32, 39.
10	Crimson Lake - -	13, 16, 24, 25, 31, 37, 38, 41, 42, 45.
1	Deep Madder - -	[See under Madders.]
1	Deep Rose - -	34.
9	Indian Red - -	7, 12, 16, 29, 31, 34, 35, 38, 39.
34	Light Red - -	1, 2, 3, 5, 6, 7, 9, 10, 15, 16, 17, 18, 19, 20, 21, 23, 24, 25, 26, 27, 28, 29, 32, 34, 35, 36, 38, 39, 40, 42, 43, 44, 45, 46.
1	Madder Carmine -	[See under Madders.]
5	„ Lake - -	„ „
2	Mars Red - -	7, 33.
3	Orange Vermilion -	24, 31, 46.
1	Permanent Crimson -	28.
3	„ Scarlet -	9, 23, 37.
9	Pink Madder - -	[See under Madders.]
3	Purple Lake - -	8, 12, 24.
34	Rose Madder - -	[See under Madders.]
1	Scarlet - -	9.
1	„ Lake - -	12.
4	„ Vermilion -	5, 11, 12, 45.
12	Venetian Red - -	4, 7, 12, 13, 14, 22, 30, 31, 33, 34, 40, 46.
31	Vermilion - -	1, 2, 3, 4, 7, 8, 10, 12, 13, 14, 15, 17, 19, 20, 21, 25, 26, 27, 29, 30, 31, 34, 35, 36, 38, 39, 40, 41, 42, 43, 44.
4	„ (Extract of) -	15, 18 (Fields), 22 (Fields), 28.
	YELLOW.	
18	Aureolin - -	3, 7, 10, 11, 19, 20, 22, 25, 27, 29, 30, 31, 32, 33, 34, 40, 43, 44.
1	Burnt Roman Ochre -	[See under Ochres.]
23	Cadmium - -	2, 3, 4, 7, 9, 11, 12, 15, 18, 20, 22, 26, 28, 30, 31, 33, 37, 38, 39, 40, 42, 44, 46.
7	„ (pale) -	3, 23, 25, 26, 27, 34, 43.
8	„ (deep) - -	3, 11, 23, 26, 27, 34, 36, 43.
1	„ Orange -	24.
4	Chrome - -	8, 16, 39, 41.
32	Gamboge - -	2, 4, 6, 7, 9, 10, 12, 14, 15, 16, 17, 21, 22, 23, 24, 25, 28, 29, 30, 31, 32, 35, 36, 37, 38, 39, 41, 42, 43, 44, 45, 46.
1	Golden Ochre -	[See under Ochres.]
11	Indian Yellow - -	5, 10, 13, 16, 23, 31, 32, 34, 39, 44, 46

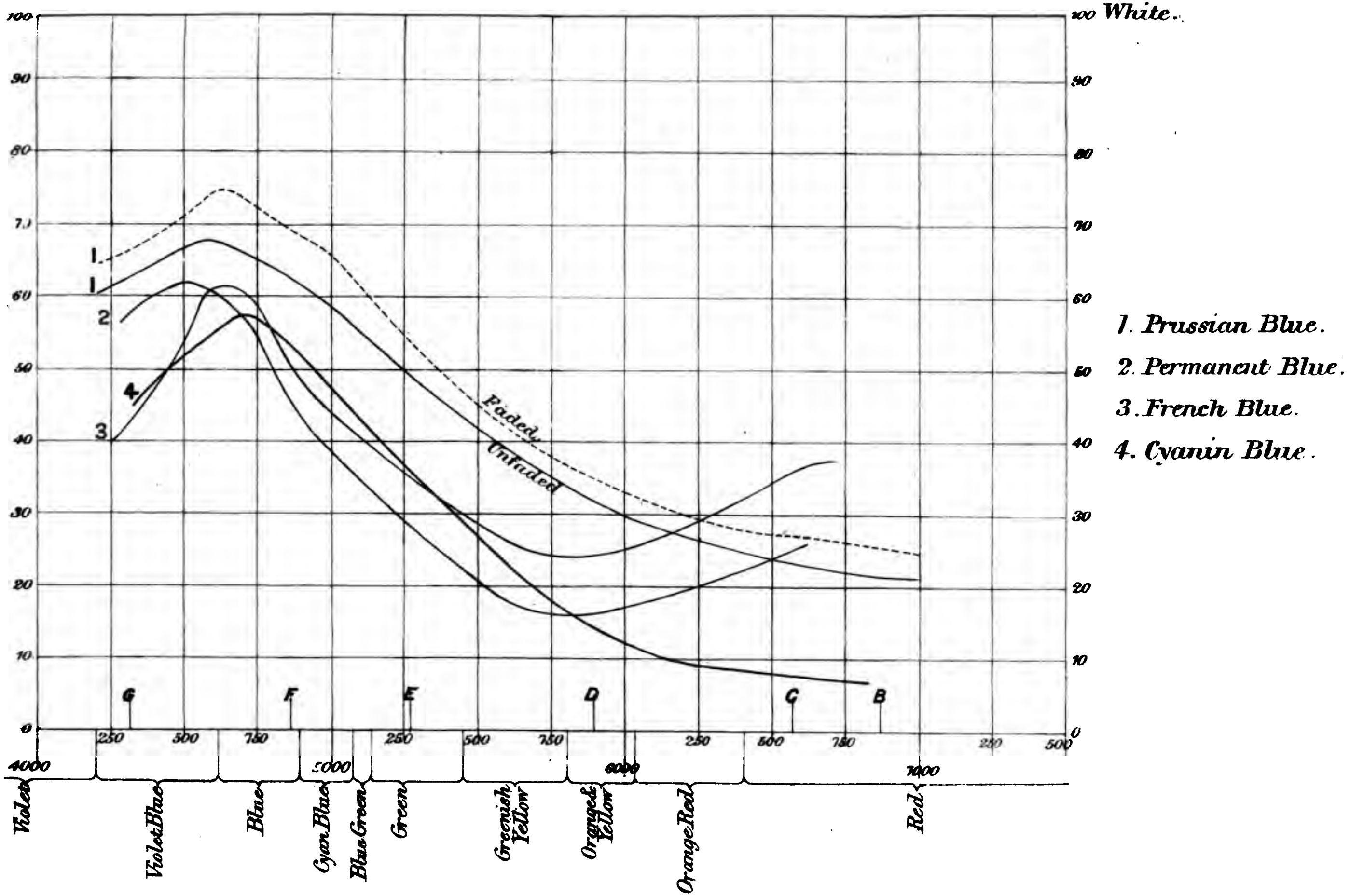
Number of Artists by whom used.	Colours.	Distinguishing Number of Artist.
	YELLOW—*continued.*	
22	Lemon (or permanent) Yellow.	2, 3, 5, 7, 9, 11, 15, 20, 21, 22, 23, 25, 26, 27, 30, 31, 33, 35, 36, 39 (Lemon and Newman's Permanent), 44, 46.
2	Mars Orange - -	32, 33.
1	„ Yellow - -	27.
1	Matrise Yellow - -	28.
2	Naples Yellow - -	16, 30.
1	Orange Chrome - -	5.
1	„ Ochre - -	[See under Ochres.]
11	Roman Ochre - -	
42	Yellow Ochre - -	
5	„ Madder - -	[See under Madders.]
1	„ Mars - -	14.
	VIOLET.	
1	Maddox Brown's Violet -	30.
	WHITE.	
12	Chinese White - -	3, 7, 10, 11, 12, 14, 22, 27, 29, 30, 31, 35.
1	Windsor and Newton's White.	37.
	MADDERS.	
33	Brown Madder - -	2, 4, 5, 6, 7, 10, 12, 14, 15, 17, 18, 20, 21, 23, 24, 25, 27, 28, 29, 31, 32, 33, 34, 35, 36, 39, 40, 41, 42, 43, 44, 45, 46.
1	Carmine Madder -	[See Madder Carmine.]
1	Deep Madder - -	9.
1	Madder Carmine -	43.
5	„ Lake - -	7, 21, 23, 33, 39.
9	Pink Madder - -	7, 9, 10, 12, 17, 23, 30, 35, 46.
13	Purple „ - -	8, 11, 17, 25, 27, 29, 32, 33, 34, 39, 42, 43, 45, 46.
4	Red „ - -	1, 17, 27, 28.
34	Rose „ - -	2, 4, 5, 6, 7, 8, 9, 11, 12, 14, 15, 16, 18, 19, 20, 22, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 36, 37, 38, 40, 42, 43, 44, 45.
4	Rubens „ - -	11, 23, 26, 40.
5	Yellow „ - -	10, 19, 26, 29, 32.
1	Madders (not otherwise defined).	3.

Number of Artists by whom used.	Colours.	Distinguishing Number of Artist.
	OCHRES.	
3	Brown Ochre	3, 27, 34.
1	Burnt Roman Ochre	17.
1	Orange Ochre	33.
1	Golden Ochre	45.
11	Roman Ochre	7, 12, 15, 17, 24, 25, 28, 29, 34, 38, 45.
42	Yellow Ochre	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 20, 21, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 45, 46.
1	The Ochres (not otherwise defined).	1.
	SIENNAS.	
41	Burnt Sienna	3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 44, 45, 46.
38	Raw Sienna	2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 32, 34, 35, 38, 40, 41, 42, 43, 44, 45, 46.
1	The Siennas (not otherwise defined).	1.
	UMBERS.	
18	Burnt Umber	3, 7, 12, 13, 14, 15, 18, 21, 22, 24, 25, 27, 33, 34, 38, 39, 40, 43.
26	Raw Umber	3, 4, 6, 7, 8, 12, 13, 15, 17, 20, 21, 23, 24, 25, 27, 28, 29, 30, 32, 33, 34, 38, 40, 42, 43, 45.
2	The Umbers (not otherwise defined).	1, 16.



Dangerfield Lith. 22, Bedford St Covent Garden. 16428 (6.88)

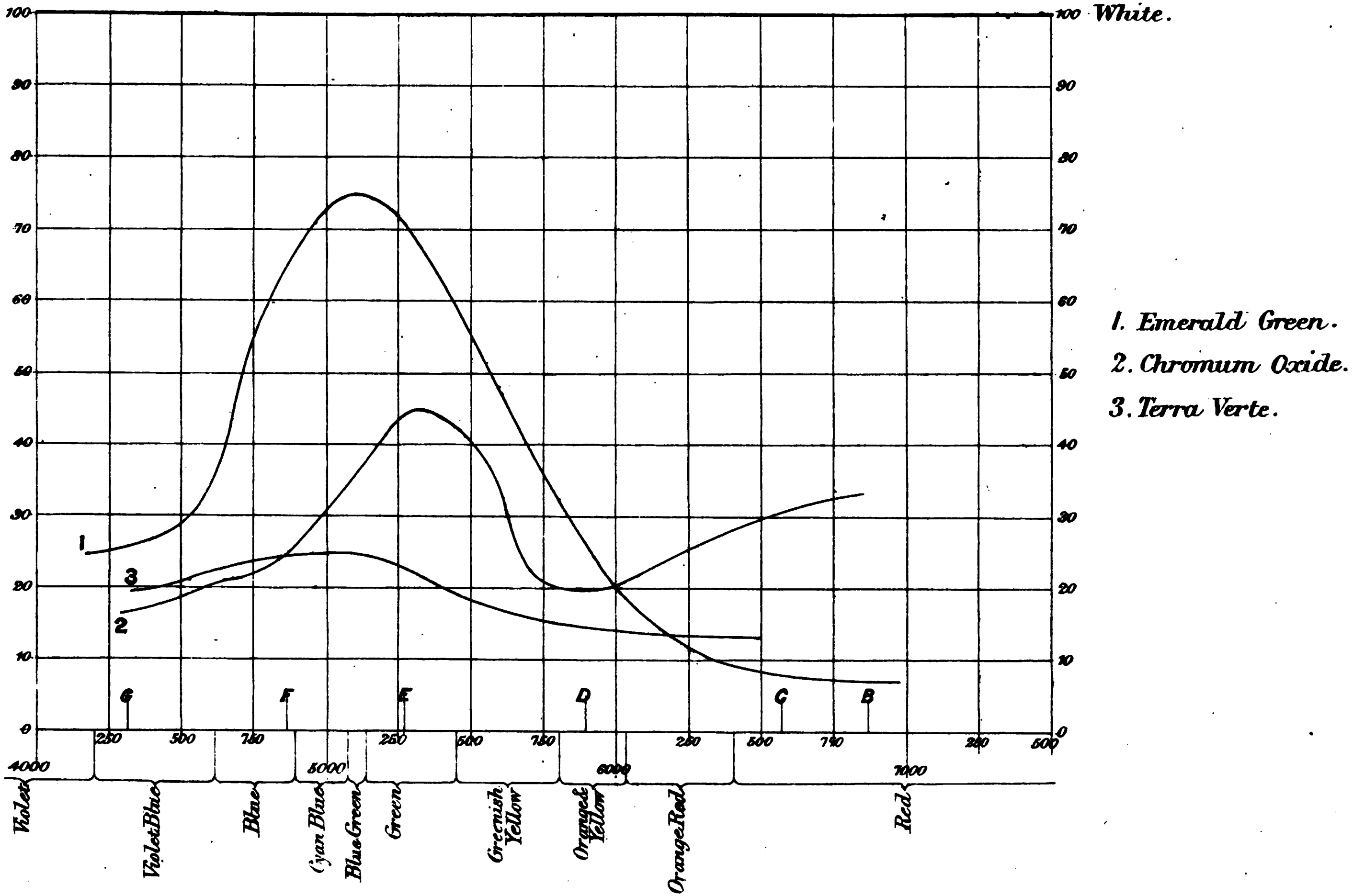
Plate II.



DANGERFIELD LITH. 22. BEDFORD ST COVENT GARDEN 16427/6.88)

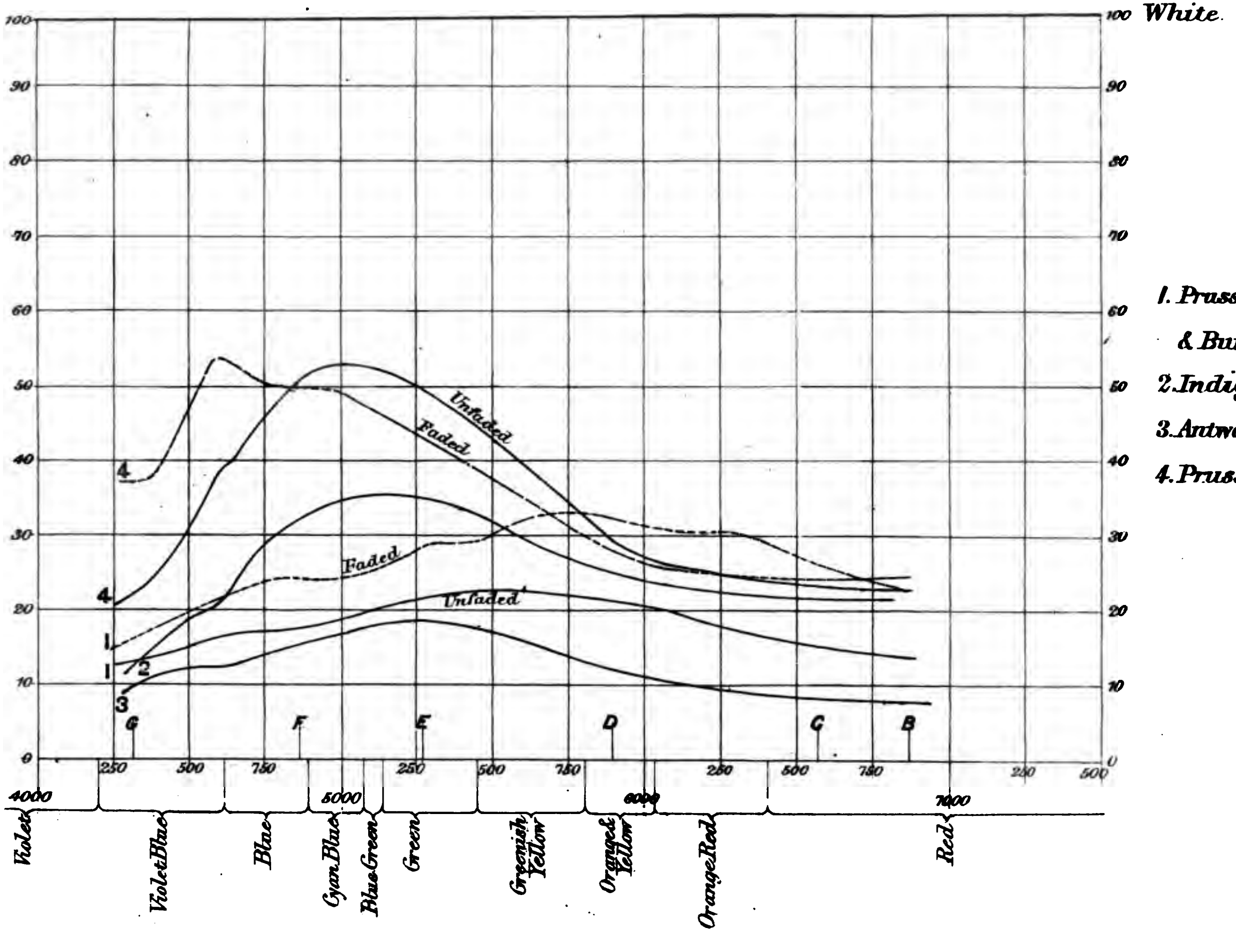
M. F. A.

Plate III.



DANGERFIELD, LITH. 22, BEDFORD ST COVENT GARDEN. 16428 (6.88)

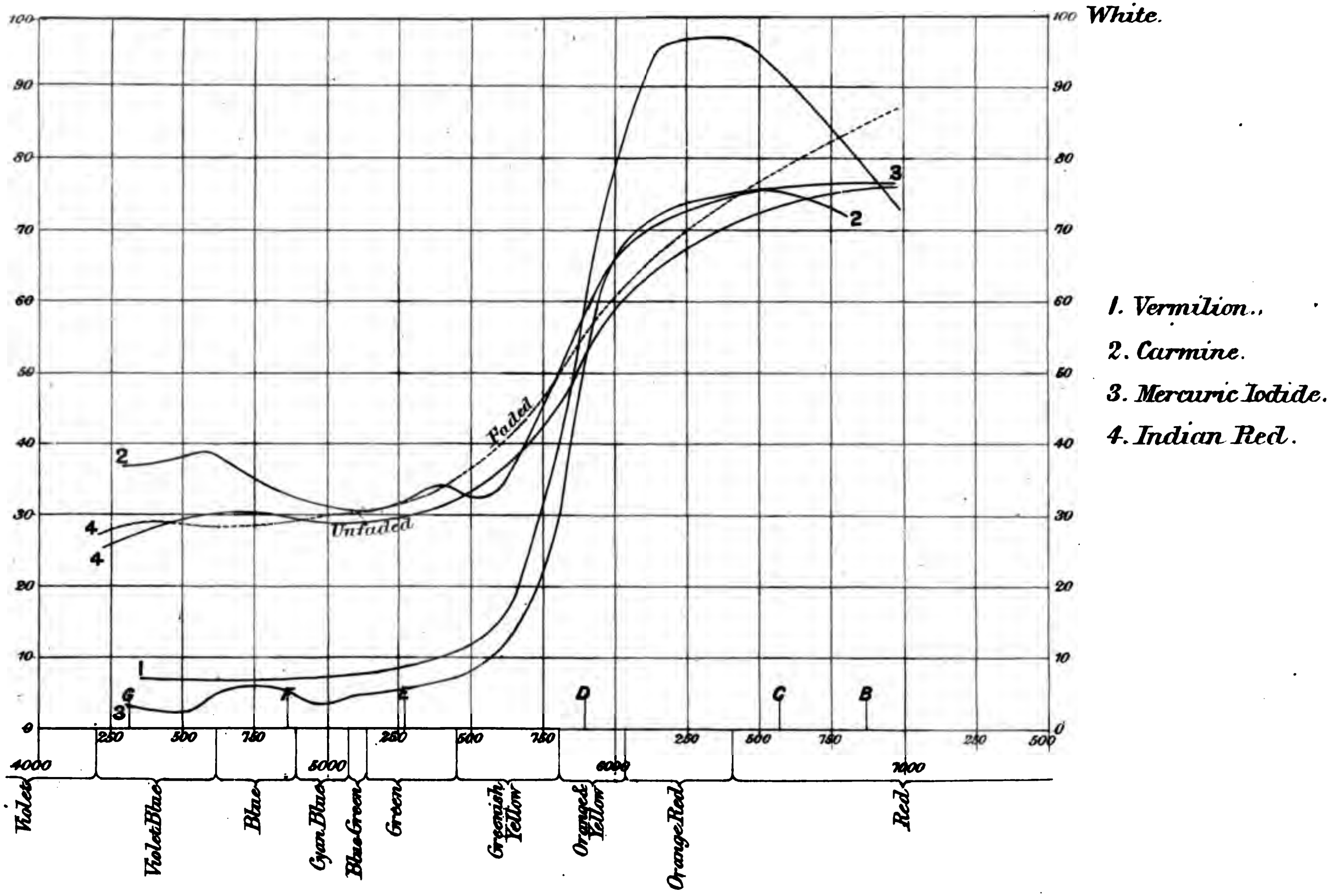
Plate IV.



1. Prussian Blue, Raw Sienna, & Burnt Sienna.
2. Indigo & Gamboge.
3. Antwerp Blue & Raw Sienna.
4. Prussian Blue & Gamboge.

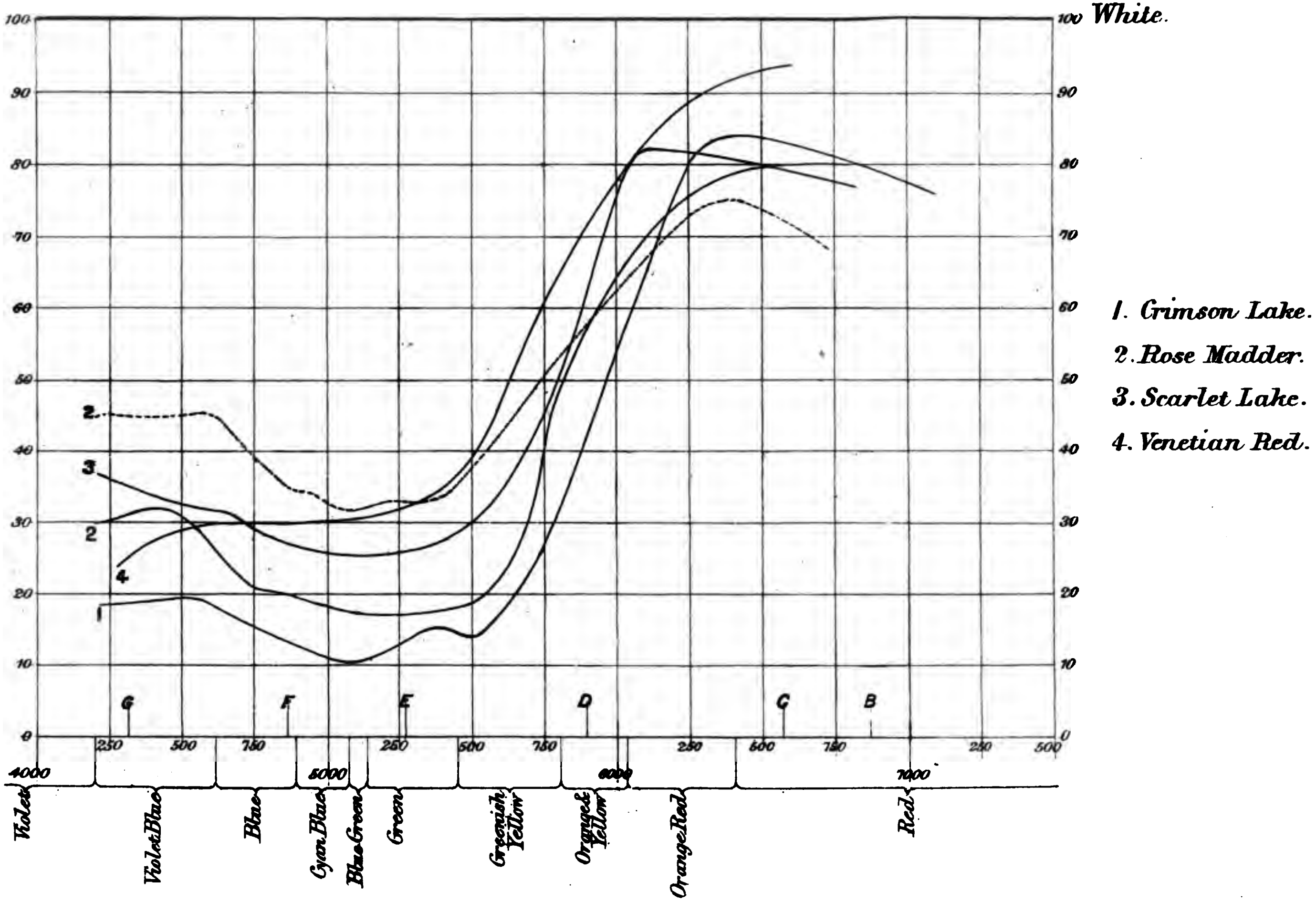
DANGERFIELD. LITH. 22, BEDFORD ST. COVENT GARDEN. 16428 (6.88)

Plate V.



Dancerfield Lith. 22, Bedford St. Covent Garden. 16428(6.88)

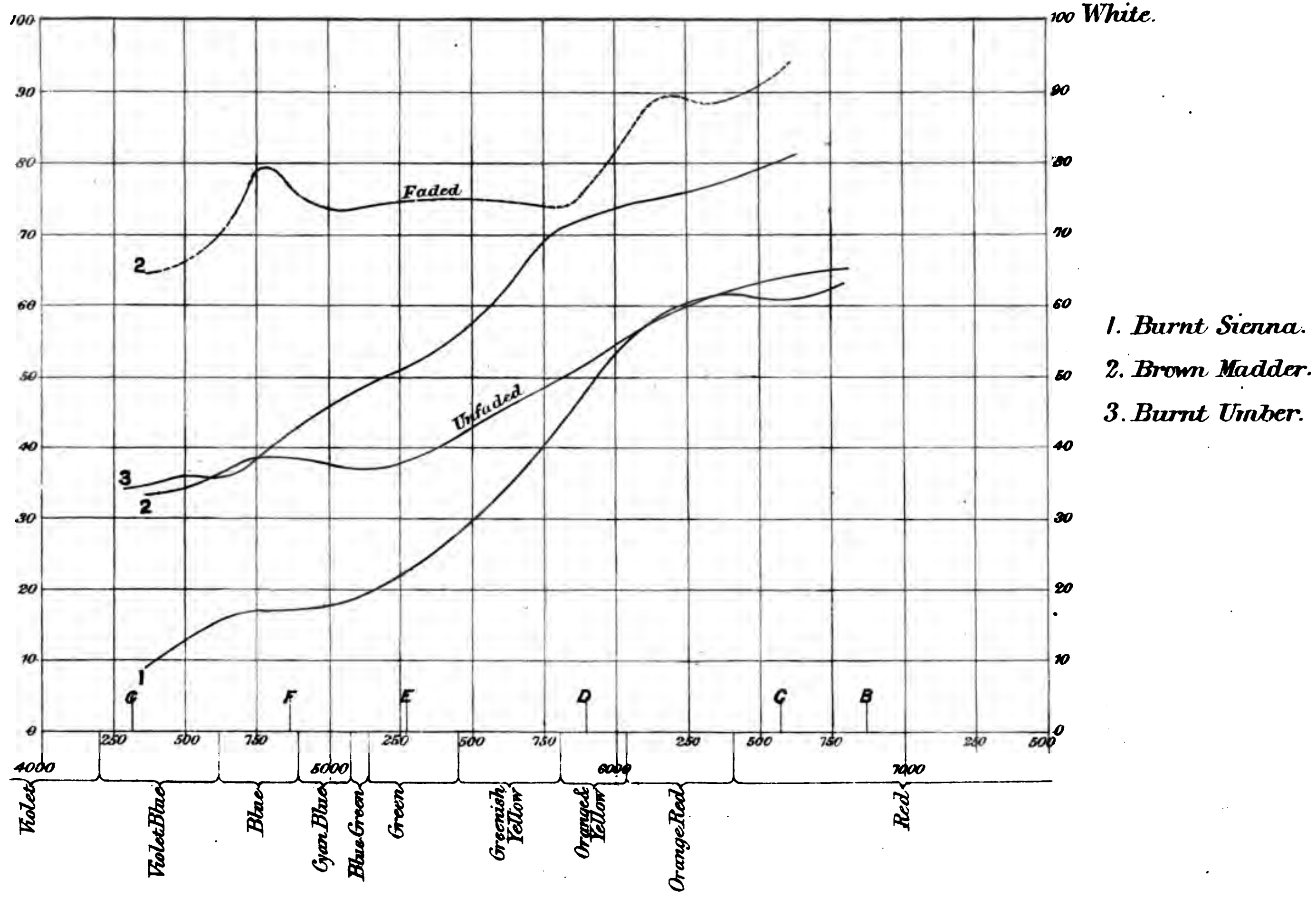
Plate VI.



DANGERFIELD, LITH. 22, BEDFORD ST COVENT GARDEN 16428 (6·88)

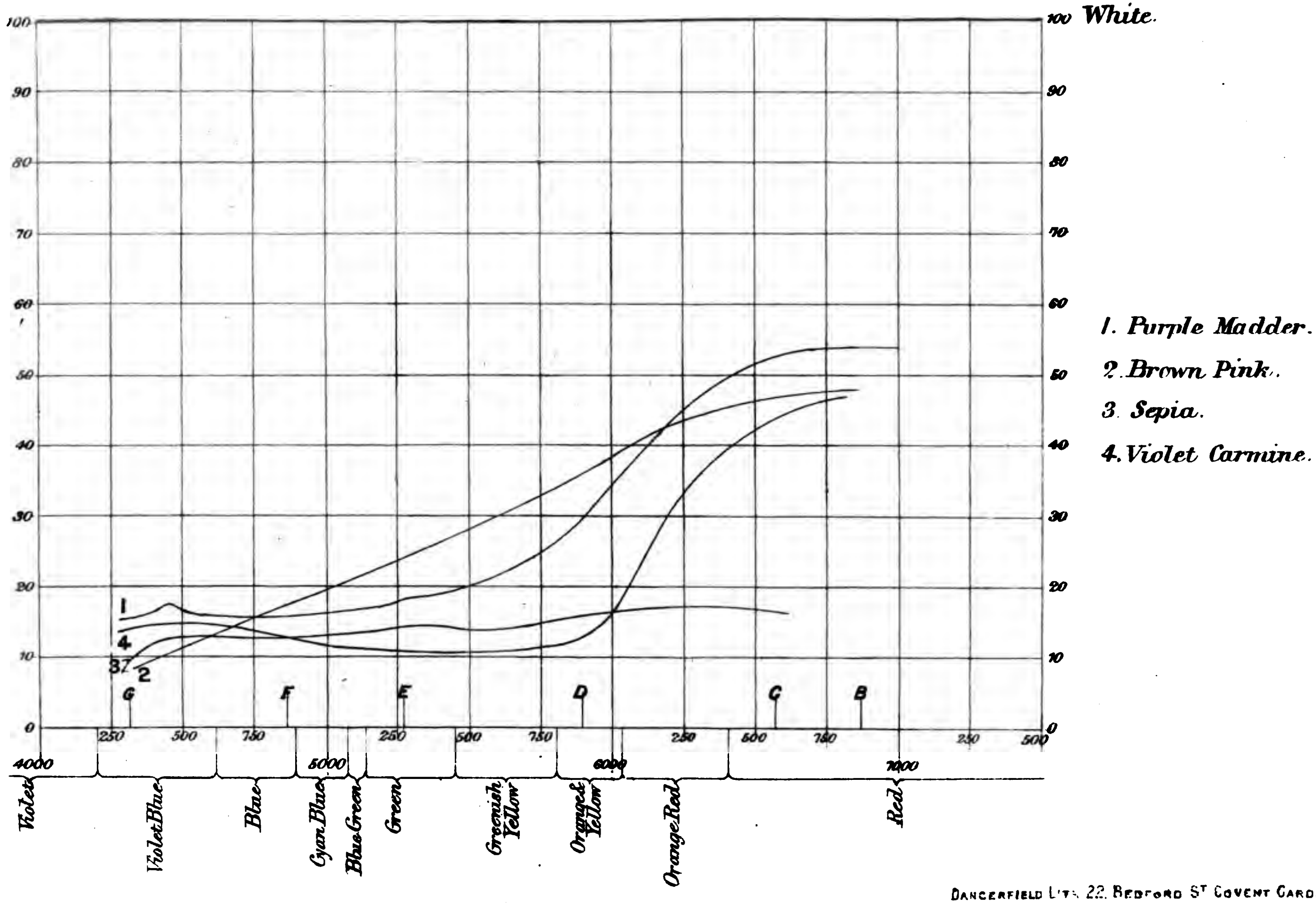
M. F. A.

Plate VII.



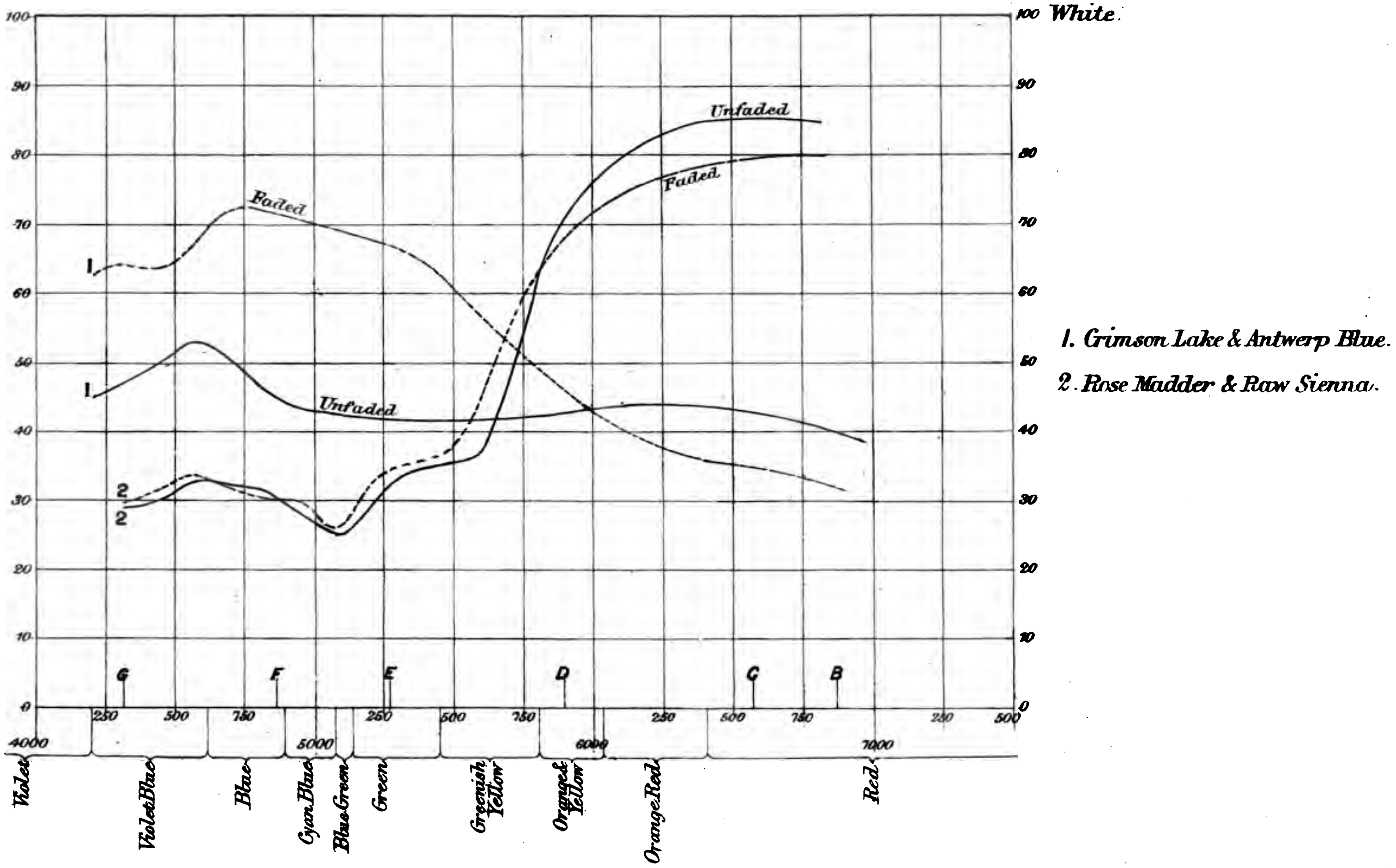
Dangerfield. Lith 22, Bedford St. Covent Garden. 16428/(6.88)

Plate VIII



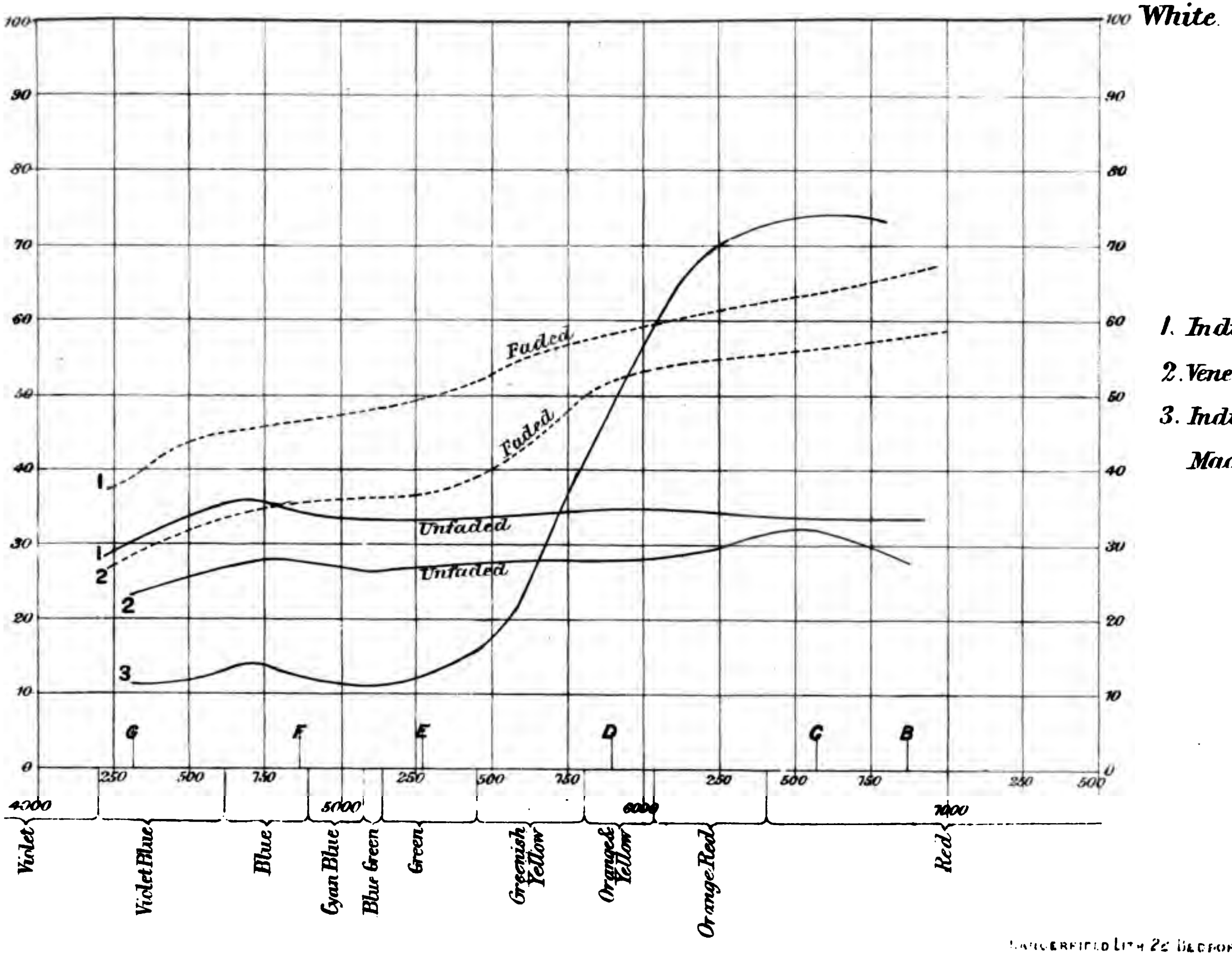
Dancerfield L^td. 22. Bedford S^t Covent Garden 16427(6.88)

Plate IX.



DANGERFIELD. LITH. 22, BEDFORD ST. COVENT GARDEN 18428(6.88)

Plate X.



1. Indian Red & Indigo.

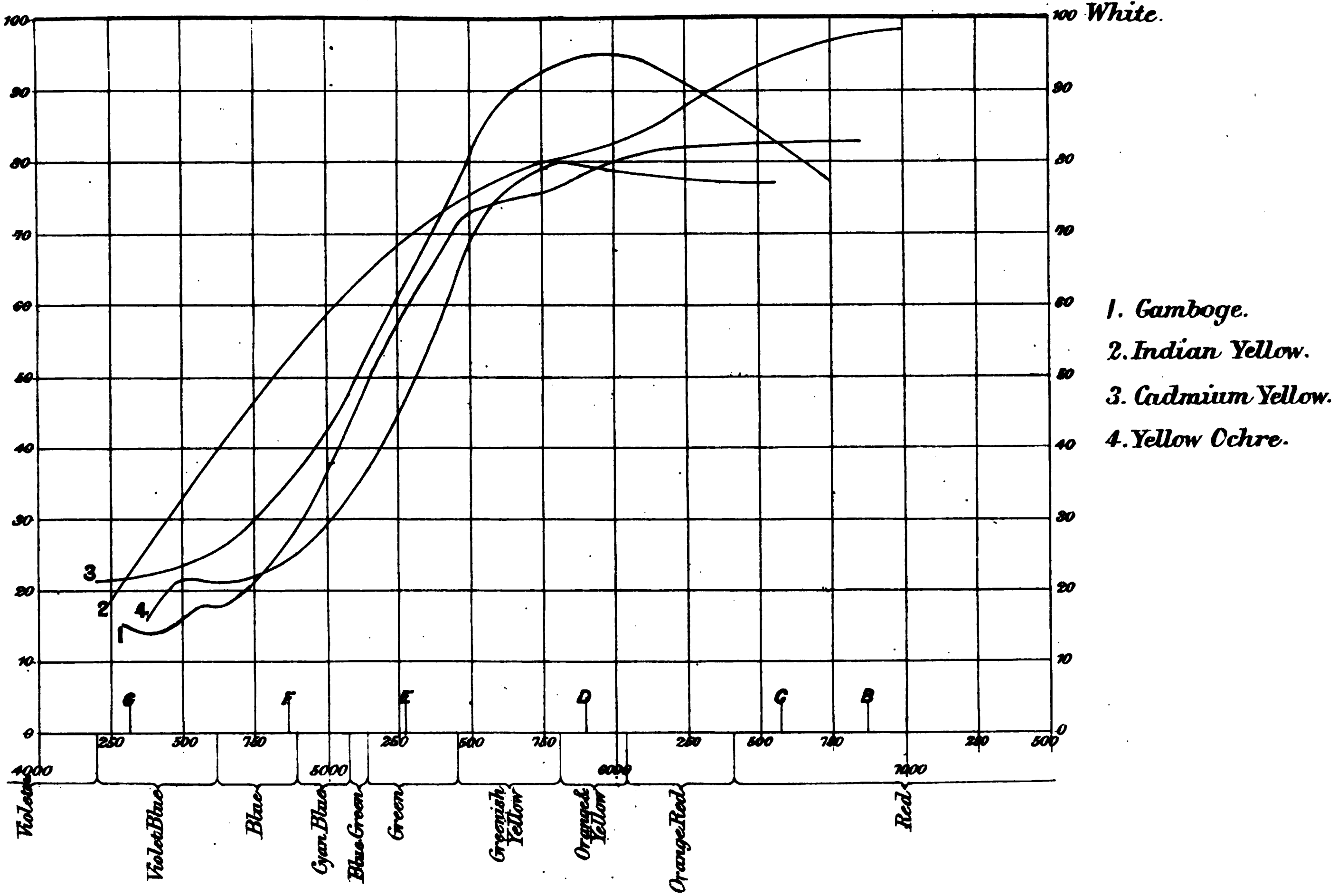
2. Venetian Red & Indigo.

3. Indian Yellow & Rose Madder.

SANGERFIELD LITH 22 BEDFORD ST COVENT GARDEN (6427 6.88)

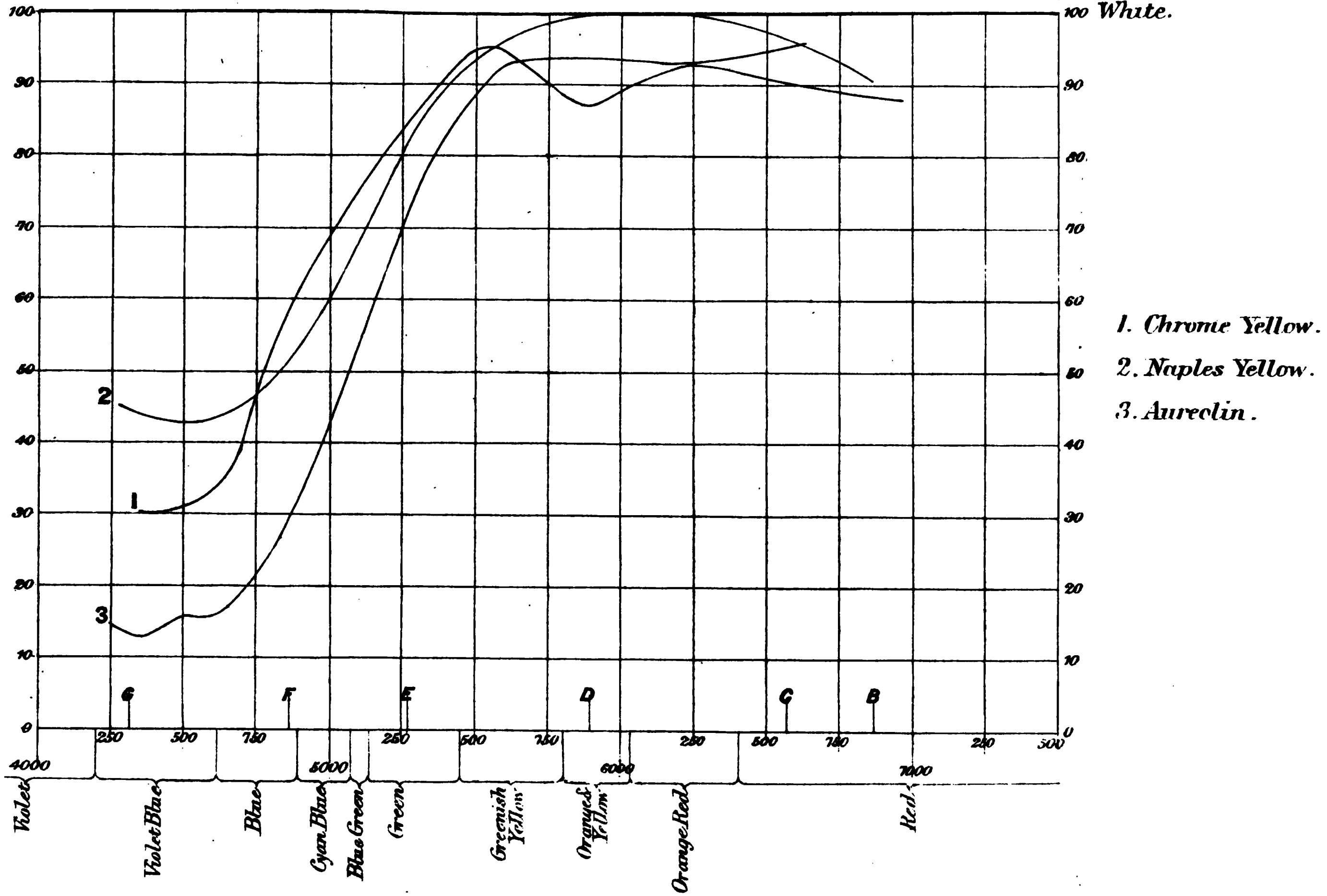
M. F. A.

Plate XI.



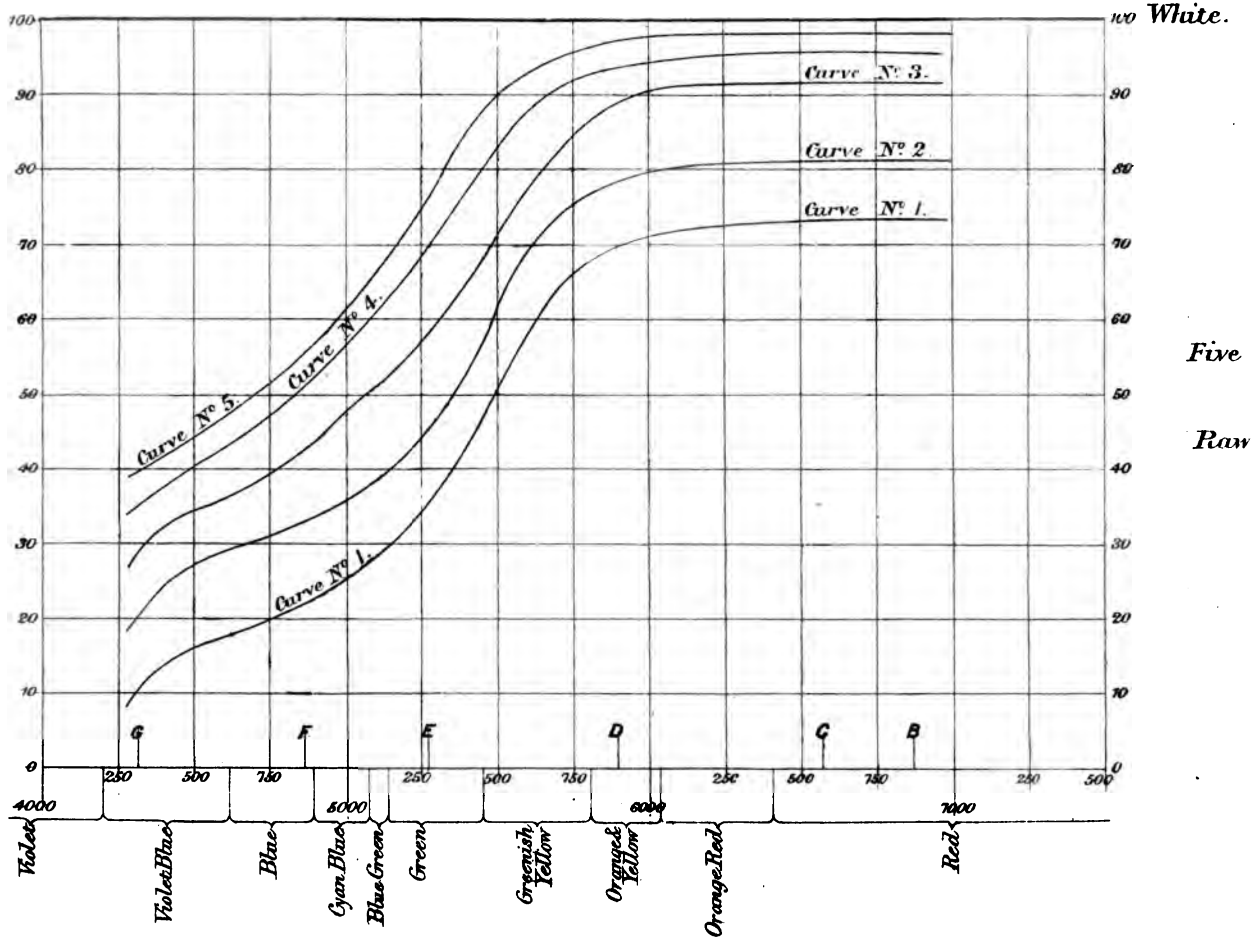
DANCERFIELD, LITH. 22, BEDFORD ST. COVENT GARDEN. 16428(6.88)

Plate XII.



DANGERFIELD LITH 22 BEDFORD ST COVENT GARDEN [illegible]

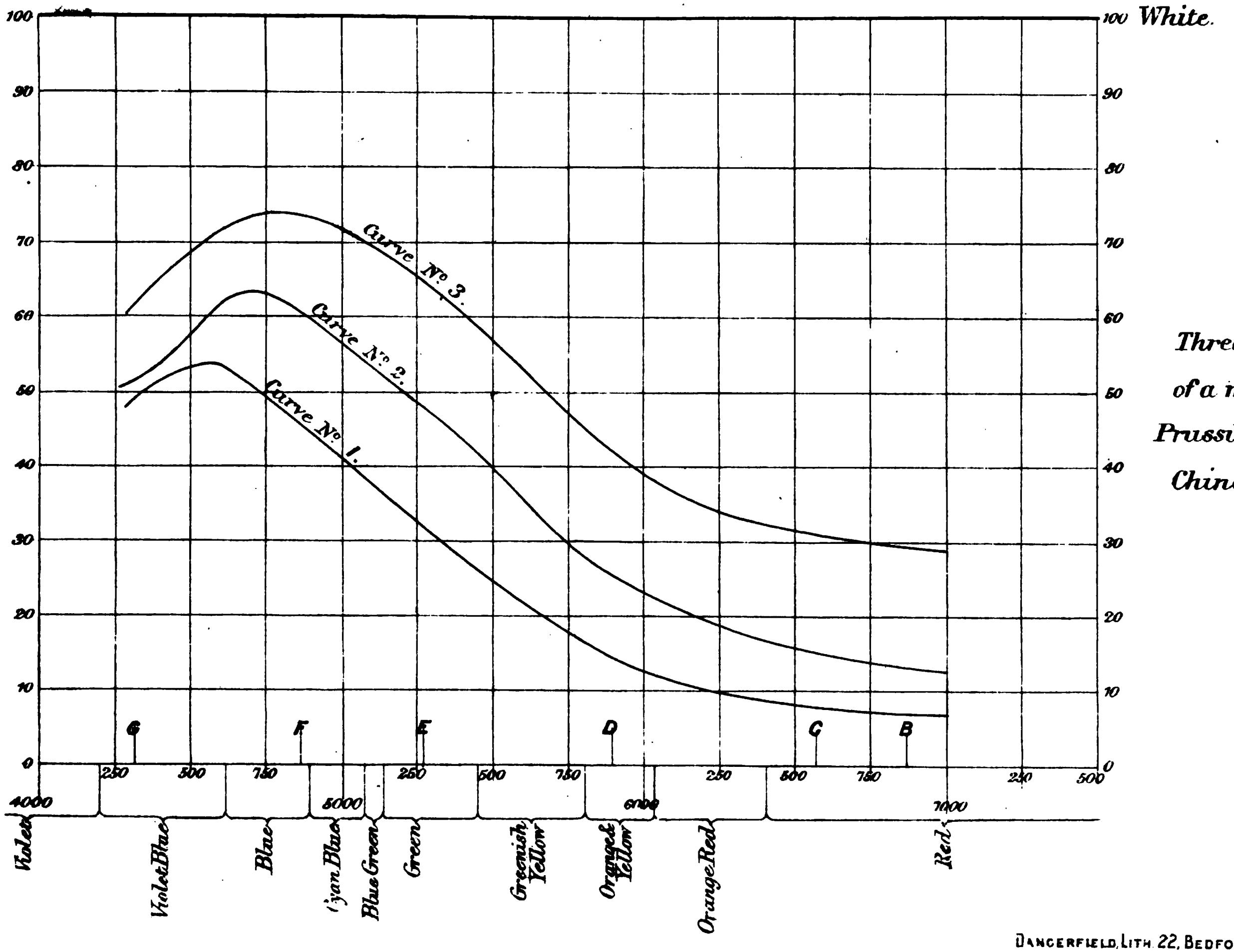
Plate XIII.



Five Shades
of
Raw Sienna

Dancerfield Lith. 22, Bedford St. Covent Garden. 16426 (6.88)

Plate XIV.



Three Shades
of a mixture of
Prussian Blue &
Chinese White.

DANGERFIELD, LITH. 22, BEDFORD ST COVENT GARDEN 16426 (6.88)

REPORT

TO THE

SCIENCE AND ART DEPARTMENT OF THE COMMITTEE OF COUNCIL ON EDUCATION

ON THE

ACTION OF LIGHT ON WATER COLOURS.

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